



## U.S. Army Corps of Engineers - Buffalo District

---

A REVISED GEOMORPHIC, SHORE PROTECTION AND NEARSHORE CLASSIFICATION OF THE LAKE ERIE, LAKE ONTARIO, NIAGARA RIVER AND ST. LAWRENCE RIVER SHORELINES

### LOWER GREAT LAKES EROSION STUDY



Submitted By:



Mr. Christian J. Stewart

ORCA TECHNOLOGIES INTERNATIONAL INC.

5325 Cordova Bay Road, Suite 211  
Victoria, British Columbia, CANADA  
V8Y 2L3

Phone: (250) 658-4844 Fax: (250) 658-0084

Contract # DACW39-97-D-0007  
Delivery Order DO05

October 1999

---



## TABLE OF CONTENTS

<b>1.0 INTRODUCTION AND BACKGROUND.....</b>	<b>2</b>
1.1 DEVELOPMENT OF ORIGINAL CLASSIFICATION.....	2
1.2 LIMITATIONS OF ORIGINAL SCHEME.....	2
1.3 OPPORTUNITIES FOR IMPROVEMENT/REVISION/RE-CLASSIFICATION.....	4
1.3.1 Lake Michigan Potential Damages Study .....	4
1.3.2 Lower Great Lakes Erosion Study.....	4
<b>2.0 RECLASSIFICATION ACTIVITIES.....</b>	<b>5</b>
<b>3.0 SHORE CLASSIFICATION SUMMARY STATISTICS .....</b>	<b>8</b>
3.1 LAKE ERIE .....	8
3.1.1 Geomorphic Shore Type.....	8
3.1.2 Shoreline Protection Classification.....	11
3.1.3 Subaqueous Nearshore Composition .....	15
3.2 LAKE ONTARIO.....	18
3.2.1 Geomorphic Shore Type.....	18
3.2.2 Shoreline Protection Classification.....	20
3.2.3 Nearshore Subaqueous Classification.....	25
3.3 NIAGARA RIVER .....	27
3.3.1 Geomorphic Shore Type.....	27
3.3.2 Shoreline Protection Classification.....	29
3.3.3 Nearshore Subaqueous Classification.....	32
3.4 ST. LAWRENCE RIVER .....	35
3.4.1 Geomorphic Shore Type.....	35
3.4.2 Shoreline Protection Classification.....	37
3.4.3 Nearshore Subaqueous Classification.....	41
<b>4.0 DISCUSSION AND RECOMMENDATIONS FOR FUTURE REFINEMENTS.....</b>	<b>44</b>
4.1 GENERAL.....	44
4.2 POTENTIAL FUTURE REFINEMENTS.....	44
4.3 RECOMMENDATIONS.....	46
<b>REFERENCES.....</b>	<b>47</b>
<b>APPENDIX I .....</b>	<b>51</b>
GREAT LAKES - ST.LAWRENCE RIVER SHORELINE CLASSIFICATION SCHEME (1999) .....	51
Geomorphic Classification.....	51
Shore Protection Classification.....	52
Nearshore Subaqueous Classification .....	53
<b>APPENDIX II.....</b>	<b>54</b>
KM x KM SHORELINE CLASSIFICATION DATA, LAKES ERIE AND ONTARIO, NIAGARA AND ST. LAWRENCE RIVERS .....	54



# **A REVISED GEOMORPHIC, SHORE PROTECTION AND NEARSHORE CLASSIFICATION OF THE LAKE ERIE, LAKE ONTARIO, NIAGARA RIVER AND ST. LAWRENCE RIVER SHORELINES**

## **LOWER GREAT LAKES EROSION STUDY**

### **1.0 Introduction and Background**

#### **1.1 Development of Original Classification**

In March of 1993, the International Joint Commission completed the 1986-1993 Reference Study of Water Level Fluctuations in the Great Lakes - St. Lawrence River basin. As part of this work, the Erosion Processes Task Group (Stewart and Pope, 1993) developed a three-tiered shoreline classification scheme for U.S. and Canadian shorelines of the Great Lakes that took into account factors related to the overall erodibility of the shoreline. These included:

1. the **geomorphic shore type** present;
2. the level of **shoreline protection** present; and
3. the geological **composition of the nearshore** zone.

This original classification was applied to all of the Great Lakes shoreline, including Lakes Erie and Ontario, and associated statistics on the various shoreline types were generated.

#### **1.2 Limitations of Original Scheme**

While the shore classification scheme and the resulting database of classification information provided a comprehensive attempt to recognize and quantify the complex nature of the Great Lakes shoreline, there were some limitations that arose, primarily due to time and budget constraints associated with the Reference Study:

- 1) The United States shoreline was classified using various published and unpublished data sources, photographs, and personal knowledge. The mappers proceeded by reviewing their materials and writing the shore type, protection level, and offshore type on U.S Geological Survey topographic quadrangles. The quadrangles were then



sent to USACE Detroit District, where the classifications were entered into a Geographical Information System (GIS) database. Note that the quadrangles were used merely as a convenient base upon which the mappers could write their classifications and notes. The shorelines in the GIS database are not based on the quadrangles but rather on recent aerial photographs. Many portions of the shore, especially along barrier spits and sandy coasts, have changed significantly since the maps were printed. In addition, man-made structures have caused major changes in some areas. This resulted in inaccuracies in shore type boundaries or misclassification of shore types.

- 2) Although the classification of several shore sections were re-evaluated to cross-check the initial classification, there was insufficient time to conduct a broad ranging quality control check. Therefore there are undoubtedly some sections of the shoreline which were mis-classified and cases where similar shores may have been interpreted into different classes.
- 3) The limited time and budget allocated to the study did not allow for additional data collection or for field verification of the classification. In addition, several different coastal geological experts were used to apply the classification scheme across the basin. This resulted in some variability in interpretation, particularly between the U.S. and Canada, and between different lakes on the U.S. side.
- 4) The variability in descriptive data throughout the literature, between states and across Canada, the limited availability of recent good-quality aerial photography and/or oblique video tapes, the lack of information on nearshore geology and bathymetry, and the generality of the classification scheme, made it impossible to assure an equal level of quality and detail in the classification across the basin.
- 5) The protection classification scheme developed for the Reference Study did not recognize the quality of the protection, only the percentage of shoreline covered. To be true to the purposes of the classification scheme, verification is needed that a "heavily protected shore" is engineered to provide a predictable design life and level of protection.
- 6) Additional data was needed on nearshore geology and bathymetry (including nearshore slope). The six classes utilized were fairly basic. Further refinements based on a better knowledge of offshore stratigraphy and lithology, as well as the degree of sand cover were required.



A number of other issues and limitations were identified in the Erosion Processes Task Group Report (Stewart and Pope, 1993).

### **1.3 Opportunities For Improvement/Revision/Re-Classification**

#### **1.3.1 Lake Michigan Potential Damages Study**

In 1997, the original classification scheme was revisited, as a result of the need for accurate and updated shoreline classification data for use in the Lake Michigan Potential Damages Study (LMPDS) which had been initiated by Detroit District USACE in late 1996. This provided an opportunity to revise and improve the classification scheme so that the above limitations could be removed, or at least significantly reduced.

In undertaking the revision of the classification scheme, a number of activities were undertaken including detailed discussions with LMPDS Study Team members (primarily staff of USACE Detroit District and CHL, and other consultants), as well as discussions with interests from other state agencies (e.g., State of Ohio, State of Illinois). This ultimately led to the development of a final revised classification scheme (see Stewart, 1997 and Appendix I).

The revised classification scheme was then applied to the Lake Michigan shoreline to produce comprehensive statistics for each of the three different classification tiers. A summary of the re-classification procedure and the Lake Michigan summary statistics can be found in a report by Stewart (1998a) prepared for Detroit District USACE.

#### **1.3.2 Lower Great Lakes Erosion Study**

In early 1998, the Buffalo District of the U.S. Army Corps of Engineers initiated a "Lower Great Lakes Erosion Study" (LGLES) along the shorelines of Lake Erie and Lake Ontario. The first phase of this study conducted in 1998, involved a thorough review, collection and analysis of a series of data related to shoreline erosion, geology, and land use.

The 1998 review and data compilation (see Stewart, 1998c) included a review and evaluation of the original IJC three-tiered shoreline classification scheme for Lake Erie and Ontario that was developed during the IJC Water Levels Reference Study between 1991-1993. In reviewing the scheme and associated data for Lake Erie and Ontario, it



became apparent that many of the limitations described above were present in the data. Two specific examples included:

- areas classified as baymouth-barrier systems that were more appropriately low banks or bluffs;
- areas classed as high, cohesive bluff shorelines, which were more accurately composite shorelines (10-12 feet of exposed erodible bedrock at the waterline, overlain by cohesive till deposits)

In light of these types of inconsistencies, a decision was made by the LGLES Study Team to apply the revised classification scheme used for Lake Michigan (Appendix I) to the Lake Erie and Ontario shoreline in order to generate the most accurate and up-to-date information possible. This would also provide data consistency with the existing classification data for Lake Michigan. There was also a desire to expand the shore classification to both the Niagara and St. Lawrence River shorelines.

The reclassification of the Lake Erie, Lake Ontario, Niagara River and St. Lawrence River shorelines took place in 1999. The remainder of this report will provide a summary of the reclassification activities that took place and will provide a series of summary statistics for the different classification tiers, for each of the four water bodies being examined.

## 2.0 Reclassification Activities

A number of activities took place in early 1999 to facilitate the re-classification of the Lake Erie and Ontario shorelines using the new shoreline classification scheme. First, in April 1999, staff of USACE Buffalo District conducted a helicopter survey of the shoreline and obtained new video-tape coverage of the entire shoreline, including the shores of the Niagara and St. Lawrence Rivers.

Second, a range of background data was collected and reviewed for key classification information. This included lithology data, geological reports, bathymetry charts, land-use maps, recent aerial photography, topographic maps, etc. A list of key data sources utilized in the Erie and Ontario re-classification exercise can be found in Table 1.

Third, a two-week "shirtsleeve" classification session was held in mid-April of 1999 with key members of the LGLES Study Team (Chris Stewart - Orca Technologies International, Rob Nairn-Baird & Associates, Joan Pope - USACE-CHL, Dave Marcus -



USACE- Buffalo, and Mike Mohr - USACE-Buffalo). At the workshop, all available materials including the video tapes, recent color aerial photography, topographic maps,

**Table 1: Data Sources For Lake Erie and Ontario Re-Classification**

DATA TYPE/NAME	SOURCE	DATE
<b>Photography</b>		
Shoreline Video Tape, Lake Erie, Ontario, Niagara and St. Lawrence Rivers	USACE Buffalo	April 1999
Shoreline Video Tape - Eastern Lake Ontario Shoreline Survey	New York Sea Grant	1995
Colour Air Photography, Lake Erie and Ontario	USACE Buffalo	1974 and 1984
Color Air Photos, State of Ohio Shoreline	Ohio DNR	1993
Oblique and Ground Level Photography	USACE Buffalo, Stewart (1998d)	Various
Large Format "Blueprint" Air Photos Lake Erie Shoreline	Southeast Michigan Council of Governments	1995
<b>Mapping</b>		
1:24,000 Topographic Maps (With Reach boundaries scribed on them)	USGS	Circa 1950s-1960s
NOAA Bathymetry Charts	USACE Buffalo	Various
IJC Reference Study Land Use and Initial Shore Classification Plots	USACE Detroit	1978 (Land Use Data)
Environmental Sensitivity Atlas for the St. Lawrence River Shorelines	Environment Canada and US Coast Guard	1994
Lake Erie Nearshore Surficial Sediments Map (Fuller and Foster, 1998)	Ohio DNR	1998
Descriptions of Sediment Samples and Cores From Michigan and Ohio Waters of Lake Erie (Herdendorf, 1978)	Ohio State University	1978
Erosion Hazard Area Maps, Ohio	Ohio DNR, Division of Geological Survey	1992



DATA TYPE/NAME	SOURCE	DATE
Erosion Hazard Maps, New York	New York Department of Environmental Conservation	1979
<b>Reports</b>		
Various Lake Erie Shoreline Geological and Flooding and Erosion Hazard Reports (Benson, 1978; Carter, 1976; Carter and Guy, 1980 and 1983; Guy, 1997; Guy, Benson and Carter, 1997a,b,c)	Ohio DNR, Division of Geological Survey	1976, 1980, 1983, 1997
Great Lakes Coastal Geology Reports (Geier and Calkin, 1983; Brennan and Calkin, 1984)	New York Sea Grant	1983, 1984
New York's Eastern Lake Ontario Sand Dunes (L.R. Johnston and Associates, 1989)	New York State Department of State	1989
New York Power Authority St. Lawrence - FDR Power Project, Shoreline Erosion and Sedimentation Study	Baird & Associates (1998)	1998
Seaway Trail Guidebook	Seaway Trail Inc.	1991
Various Journal Articles and Other Literature	Teresmae (1965), Occhietti (1989), Pair et al. (1990), Sutton et al. (1970), Calkin and Muller (1992), Calkin et al. (1982), Gillette and Dollen, (1940)	Various

land use maps, reports and other data were made available. Proceeding kilometer-by-kilometer along the shoreline, the reclassification team examined all the data and recorded new classification information on hardcopy maps with reach boundaries noted on them.

In conducting the classification for Lake Erie and Ontario and the Niagara and St. Lawrence Rivers, two minor changes were made to the classification methodology, both of which applied to the shore protection category.



First, an estimate was made of the percentage of each reach that was protected, where shore protection structures were noted. This was recorded as a separate item in the overall database and a new field in the Recession Rate Analysis System being developed elsewhere in the Study by OTI.

Second, there is a significant concentration of recreational boating activities in both the St. Lawrence River and Lake Ontario, which results in the presence of a number of marina docks and private boat docks along the shoreline. In order to capture these in the shore protection classification system, they were classed as shore protection Type 2B2 (Jetty, 5-45 year lifespan). This differentiates them from Type 2B1 Jetties, which apply only to major jetty structures located at harbor entrances.

Following the workshop, the hardcopy information was converted into a kilometer-by-kilometer spreadsheet (Appendix II) and was checked against the map sheets for data accuracy and quality. Associated statistics on shore type, shore protection level and nearshore type were then generated. This new shoreline classification data was incorporated into the latest version of the Recession Rate Analysis System that is being developed in a separate activity by OTI for USACE Buffalo.

Summary statistics for each of the shoreline classification categories are presented in the following section.

### **3.0 Shore Classification Summary Statistics**

Shoreline classification data generated during the reclassification activities were entered into an MS Excel spreadsheet for analysis purposes. Summary statistics generated include the number of kilometers of shoreline falling into the classification category as well as the associated percentage of shoreline falling in the same category. Summary tables, histograms and pie charts were also generated to provide visual interpretations of the data.

#### **3.1 Lake Erie**

##### **3.1.1 Geomorphic Shore Type**

Table 2 presents summary statistics of the number of kilometers of each of the geomorphic shore type categories found for the Lake Erie shoreline. These are further



illustrated by the histogram in Figure 1 and the pie chart illustrating the percentages in each category in Figure 2.

**Table 2 - Lake Erie Geomorphic Shore Type Classification**

Shore Type	Km's of Coast
<b>1. Sand or Cohesive Homogeneous Bluffs</b>	
1A - Homogeneous Bluffs Sand Content 0-20%	51
1B - Homogeneous Bluffs Sand Content 20-50%	46
1C - Homogeneous Bluffs Sand Content >50%	2
1D - Composite Bluffs Sand Content 0-20%	24
1E - Composite Bluffs Sand Content 20-50%	110
1F - Composite Bluffs Sand Content >50%	0
<b>2. Sand or Cohesive Bluffs With Beach</b>	
2A - Homogeneous Bluffs Sand Content 0-20%	5
2B - Homogeneous Bluffs Sand Content 20-50%	2
2C - Homogeneous Bluffs Sand Content >50%	3
2D - Composite Bluffs Sand Content 0-20%	0
2E - Composite Bluffs Sand Content 20-50%	7
2F - Composite Bluffs Sand Content >50%	0
<b>3. Low Bank</b>	
3A - Sand Content 0-20%	54
3B - Sand Content 20-50%	21
3C - Sand Content >50%	13
<b>4 - Baymouth Barrier</b>	71
<b>5 - Sandy Beach / Dune</b>	63
<b>6 - Coarse Beaches</b>	12
<b>7 - Bedrock (Resistant)</b>	16
<b>8 - Bedrock (Non-Resistant)</b>	82
<b>9 - Open Shoreline Wetlands</b>	49
<b>10 - Artificial</b>	189
<b>11 - Unclassified</b>	0
<b>Total</b>	<b>820</b>



### Lake Erie Shore Type Classification (By Total Km)

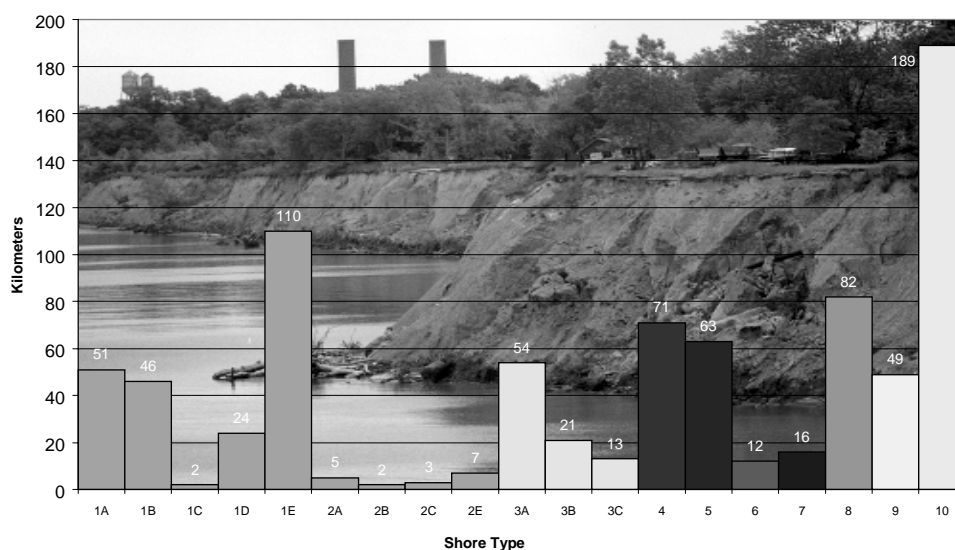


Figure 1 - Lake Erie Shore Type - By Kilometer

### Lake Erie Shore Type Classification (By Percentage)

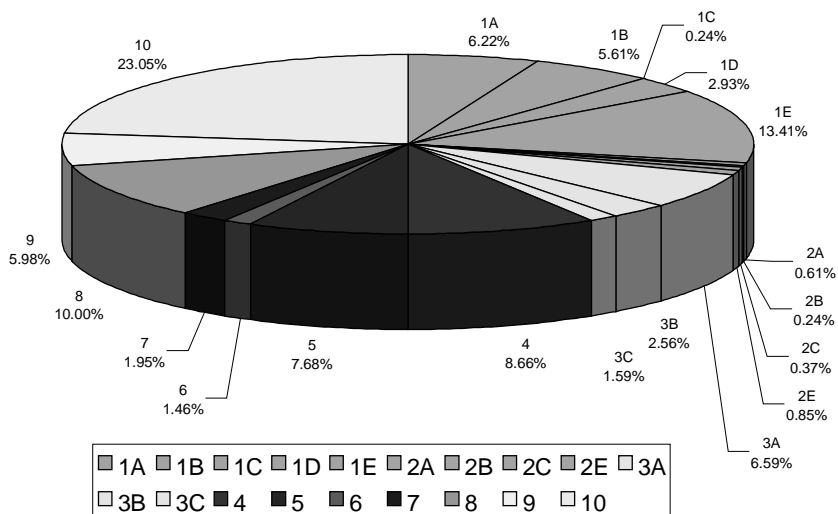


Figure 2 - Lake Erie Shore Type - By Percentage



"Sand or Cohesive Homogenous Bluffs" (Shore Type 1A-F) predominate along the Lake Erie shoreline, occupying over 28% (233km) of the entire shoreline. The majority of this (110km) is comprised of Shore Type 1E - "Composite Bluffs Sand Content 20-50%." This is followed closely by the Artificial category, which makes up over 23% (189 km) of the shoreline. The high predominance of the artificial category is due to heavy shore protection, harbor structures and land fill in major urban areas such as Buffalo, Erie, Ashtabula, Cleveland, Sandusky and Toledo. "Beach" type shorelines (Types 4-6) occupy over 17% of the shoreline and are comprised mainly of Baymouth-Barriers (8.6%) and Sandy Beach-Dune (7.6%). Bedrock shorelines are important along the Lake Erie coast, occupying almost 11% of the shoreline, most of which (10%) falls into the erodible or "Non-Resistant" bedrock category (Type 8). Low bank shorelines (Types 3A-C) occupy approximately 10% of the shoreline.

### 3.1.2 Shoreline Protection Classification

Table 3 presents summary statistics of the number of kilometers of each of the shoreline protection type categories found for the Lake Erie shoreline. These are further illustrated by the histograms in Figures 3 and 4 and the pie charts illustrating the percentages in each category in Figures 5 and 6.

**Table 3 - Lake Erie Shoreline Protection Classification**

Shore Protection Type	KMs of Coast
<b>1. Coastal Armoring</b>	
1A1 - Revetments >45 year lifespan	142
1A2 - Revetments 5-45 year lifespan	206
1A3 - Revetments 0-5 year lifespan	9
1A4 - Revetments 0 year lifespan (disrepair)	0
1B1 - Seawalls/Bulkheads >45 year lifespan	95
1B2 - Seawalls/Bulkheads 5-45 year lifespan	200
1B3 - Seawalls/Bulkheads 0-5 year lifespan	3
1B4 - Seawalls/Bulkheads 0 year lifespan (disrepair)	0
<b>2. Beach Erosion Control Devices</b>	
2A1 - Groins >45 year lifespan	5



## U.S. Army Corps of Engineers - Buffalo District

2A2 - Groins 5-45 year lifespan	82
2A3 - Groins 0-5 year lifespan	13
2A4 - Groins 0 year lifespan (disrepair)	0
2B1 - Jetties >45 year lifespan	89
2B2 - Jetties 5-45 year lifespan	27
2B3 - Jetties 0-5 year lifespan	0
2B4 - Jetties 0 year lifespan (disrepair)	0
2C1 - Offshore Breakwaters >45 year lifespan	112
2C2 - Offshore Breakwaters 5-45 year lifespan	19
2C3 - Offshore Breakwaters 0-5 year lifespan	0
2C4 - Offshore Breakwaters 0 year lifespan (disrepair)	0
<b>3. Non-Structural</b>	
3A1 - Beach Nourishment >45 year lifespan	2
3A2 - Beach Nourishment 5-45 year lifespan	0
3A3 - Beach Nourishment 0-5 year lifespan	0
3A4 - Beach Nourishment 0 year lifespan (disrepair)	0
3B1 - Vegetation Planting >45 year lifespan	0
3B2 - Vegetation Planting 5-45 year lifespan	0
3B3 - Vegetation Planting 0-5 year lifespan	0
3B4 - Vegetation Planting 0 year lifespan (disrepair)	0
3C1 - Slope/Bluff Stabilization >45 year lifespan	1
3C2 - Slope/Bluff Stabilization 5-45 year lifespan	9
3C3 - Slope/Bluff Stabilization 0-5 year lifespan	11
3C4 - Slope/Bluff Stabilization 0 year lifespan (disrepair)	0
<b>4. Protected Wetlands</b>	
	67
<b>5. Ad-Hoc Structures</b>	
5A1 - Concrete Rubble >45 year lifespan	0
5A2 - Concrete Rubble 5-45 year lifespan	2
5A3 - Concrete Rubble 0-5 year lifespan	25
5A4 - Concrete Rubble 0 year lifespan (disrepair)	0
5B1 - Other Materials >45 year lifespan	0
5B2 - Other Materials 5-45 year lifespan	4
5B3 - Other Materials 0-5 year lifespan	4
5B4 - Other Materials 0 year lifespan (disrepair)	0
<b>6 - Unclassified</b>	
	0

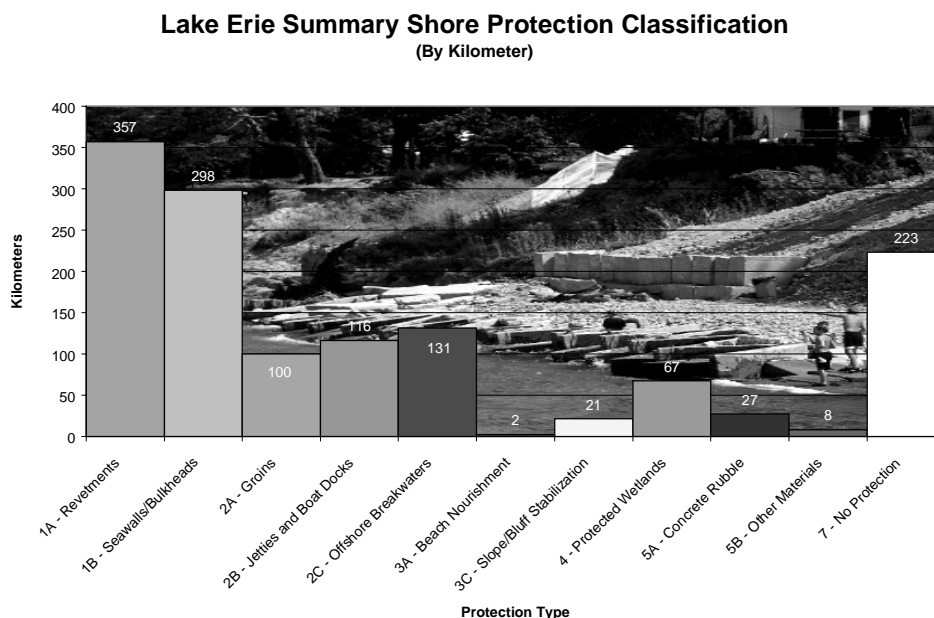


## U.S. Army Corps of Engineers - Buffalo District

<b>7 - No Protection</b>	223
<b>Grand Total*</b>	1350

\*Note: More than one shore protection type was recorded for each kilometer reach for many cases along the shoreline. As a result, the total kilometers for shore protection add up to more than the total length of the Lake Erie shoreline.

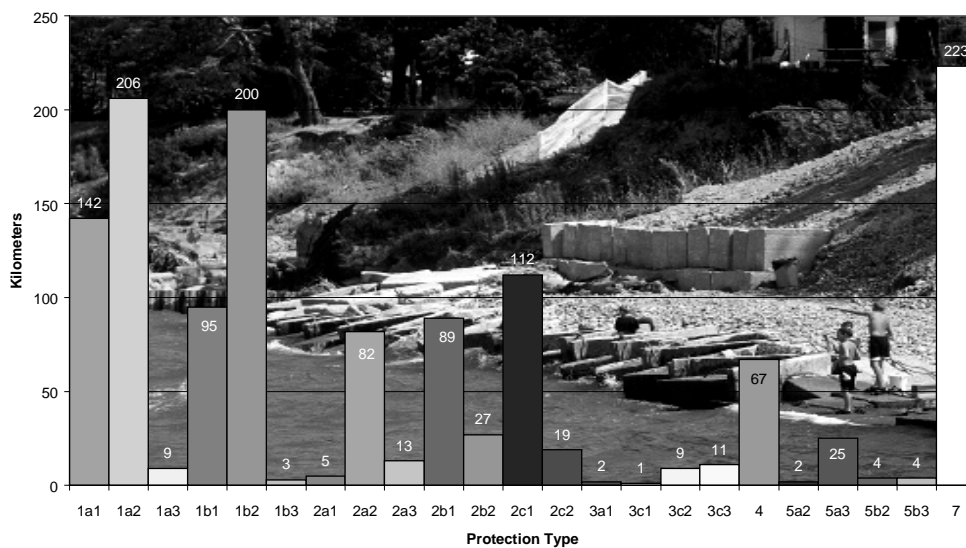
Lake Erie has a wide variety of shore protection structures along its shoreline, although there is a dominance of revetments and seawalls (Types 1A and 1B), as almost 80% (655 of 820 reaches) had this type of shore protection occurring in them. Of these, the majority fell into the medium quality category (i.e., 1A2 and 1B2) and represented various private property owner structures. Over 27% of the shoreline (223 reaches) was classed as unprotected. Offshore breakwaters (Type 2C) were the next dominant shore protection type, occurring in 131 of the 820 reaches, representing 16% of the total shoreline. The bulk of these are the various offshore structures in place at Presque Isle in Erie, Pa. The highly urbanized and industrialized nature of the Lake Erie shoreline (e.g.,



**Figure 3 - Lake Erie Shore Protection Summary (By Kilometer)**

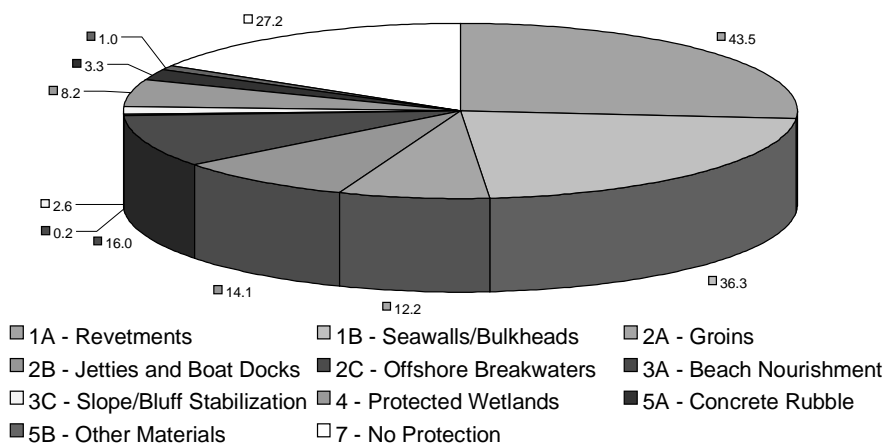


**Lake Erie Detail Shore Protection Classification**  
(By Kilometer)

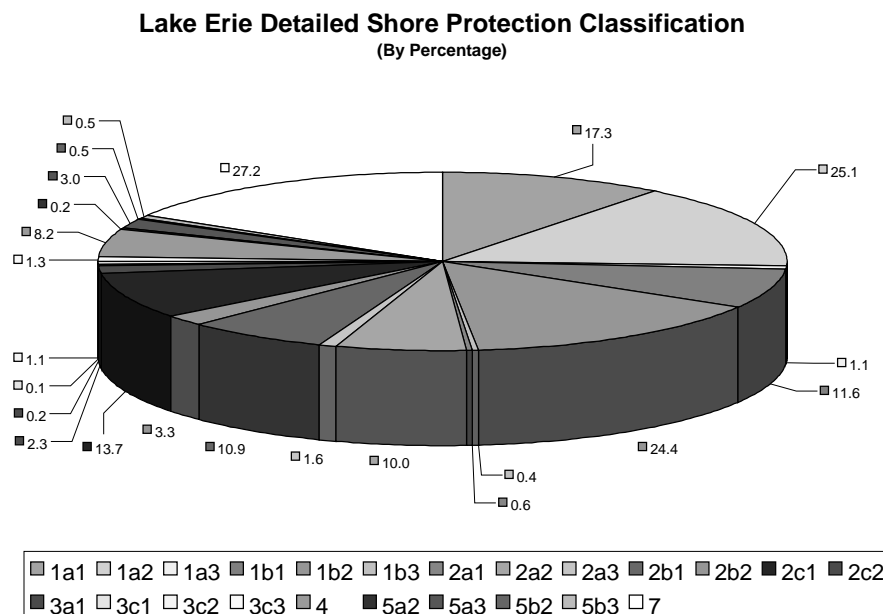


**Figure 4 - Lake Erie Shore Protection Detail (By Kilometer)**

**Lake Erie Summary Shore Protection Classification**  
(By Percentage)



**Figure 5 - Lake Erie Shoreline Protection Summary (By Percentage)**



**Figure 6 - Lake Erie Shoreline Protection Detail (By Percentage)**

Buffalo, Erie, Ashtabula, Cleveland, Sandusky, Toledo) is reflected in a significant number of jetties (Type 2B1) being present (89 reaches or almost 11% of the shore), as well as a high percentage of high quality revetments (Type 1A1)(142 reaches, 17.3%) and seawalls (Type 1B1)(95 reaches, 11.6%). Another notable category is the presence of 67 km of protected wetlands (Type 4), representing just over 8% of the total shoreline, the majority of which occur in the western portion of the Lake Erie basin.

### 3.1.3 Subaqueous Nearshore Composition

Table 4 presents summary statistics of the number of kilometers of each of the Nearshore Subaqueous type categories found for the Lake Erie shoreline. These are further illustrated by the histogram in Figures 7 and the pie charts illustrating the percentages in Figures 8.



**Table 4 - Lake Erie Nearshore Subaqueous Classification**

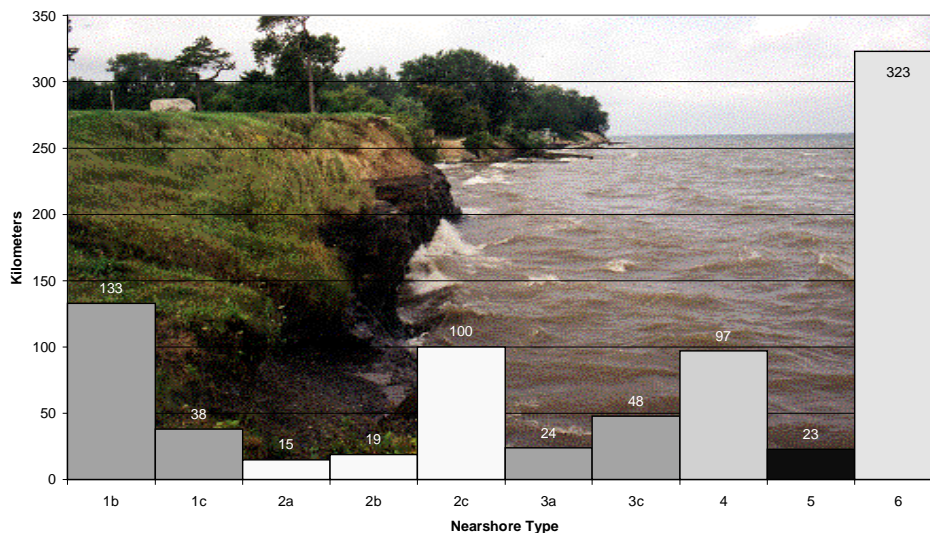
Nearshore Class	Kms of Coast
<b>1. Cohesive (Till)</b>	
1A - Thick Sand Cover (>200m <sup>3</sup> /m)	0
1B - Moderate Sand Cover (50-200 m <sup>3</sup> /m)	133
1C - Thin Sand Cover (<50 m <sup>3</sup> /m)	38
<b>2. Cohesive (Lacustrine Clay)</b>	
2A - Thick Sand Cover (>200m <sup>3</sup> /m)	15
2B - Moderate Sand Cover (50-200 m <sup>3</sup> /m)	19
2C - Thin Sand Cover (<50 m <sup>3</sup> /m)	100
<b>3. Cobble/Boulder Lag Over Cohesive</b>	
3A - Thick Sand Cover (>200m <sup>3</sup> /m)	24
3B - Moderate Sand Cover (50-200 m <sup>3</sup> /m)	0
3C - Thin Sand Cover (<50 m <sup>3</sup> /m)	48
<b>4 - Sandy</b>	97
<b>5 - Bedrock (Resistant)</b>	23
<b>6 - Bedrock (Non-Resistant)</b>	323
<b>7 - Unclassified</b>	0
Total	820

The Lake Erie nearshore zone is dominated by 323 kilometers of erodible or non-resistant bedrock (Type 6), covering almost 40% of the total shoreline length. This nearshore type dominates between Buffalo and Presque Isle in the eastern portion of the basin.

Cohesive till with moderate sand cover (Type 1B) is the next predominant (133km or 16%), followed by cohesive lacustrine clay with thin sand cover (Type 2C)(100km or 12%) and then sandy (Type 4)(97km or almost 12%). Also of note relative to the effects of water levels on shoreline response, over 70km of the shoreline falls into the cobble/boulder lag over cohesive class (Type 3a and 3c).

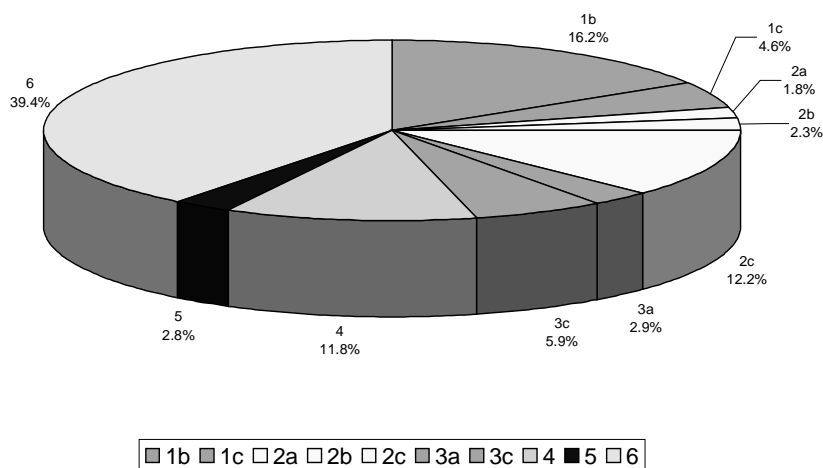


**Lake Erie Nearshore Subaqueous Classification**  
(By Kilometer)



**Figure 7 - Lake Erie Nearshore Subaqueous Classification (By Kilometer)**

**Lake Erie Nearshore Subaqueous Classification**  
(By Percentage)



**Figure 8 - Lake Erie Nearshore Subaqueous Classification (By Percentage)**



## 3.2 Lake Ontario

### 3.2.1 Geomorphic Shore Type

Table 5 presents summary statistics of the number of kilometers of each of the geomorphic shore type categories found for the Lake Ontario shoreline. These are further illustrated by the histogram in Figure 9 and the pie chart illustrating the percentages in each category in Figure 10.

**Table 5 - Lake Ontario Geomorphic Shore Type Classification**

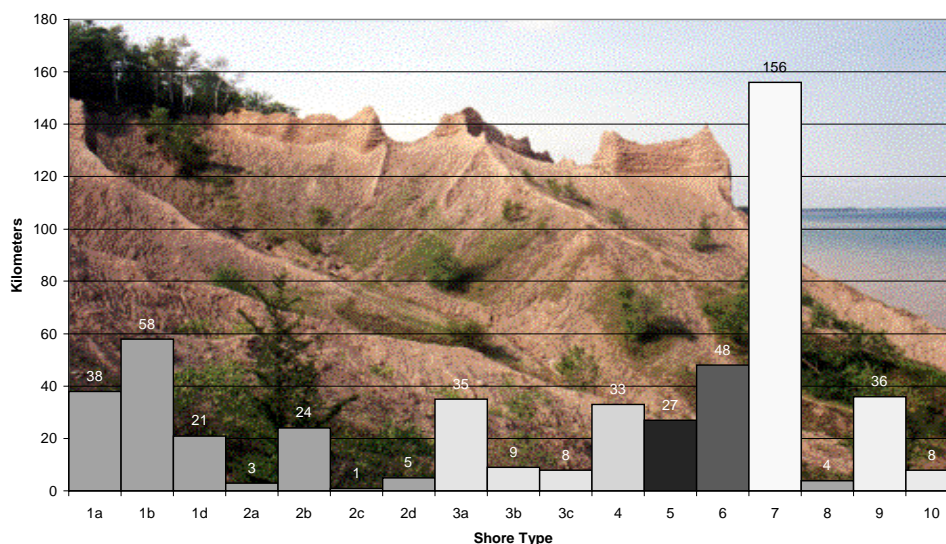
Shore Type	Km's of Coast
<b>1. Sand or Cohesive Homogeneous Bluffs</b>	
1A - Homogeneous Bluffs Sand Content 0-20%	38
1B - Homogeneous Bluffs Sand Content 20-50%	58
1C - Homogeneous Bluffs Sand Content >50%	0
1D - Composite Bluffs Sand Content 0-20%	21
1E - Composite Bluffs Sand Content 20-50%	0
1F - Composite Bluffs Sand Content >50%	0
<b>2. Sand or Cohesive Bluffs With Beach</b>	
2A - Homogeneous Bluffs Sand Content 0-20%	3
2B - Homogeneous Bluffs Sand Content 20-50%	24
2C - Homogeneous Bluffs Sand Content >50%	1
2D - Composite Bluffs Sand Content 0-20%	5
2E - Composite Bluffs Sand Content 20-50%	0
2F - Composite Bluffs Sand Content >50%	0
<b>3. Low Bank</b>	
3A - Sand Content 0-20%	35
3B - Sand Content 20-50%	9
3C - Sand Content >50%	8
<b>4 - Baymouth Barrier</b>	33
<b>5 - Sandy Beach / Dune</b>	27
<b>6 - Coarse Beaches</b>	48
<b>7 - Bedrock (Resistant)</b>	156



8 - Bedrock (Non-Resistant)	4
9 - Open Shoreline Wetlands	36
10 - Artificial	8
11 - Unclassified	0
Total	514

Lake Ontario is predominated by over 150km (30%) of resistant bedrock shoreline (Type 7) all of which is found in the northeast portion of the lake extending from Cape Vincent, to just north of the Eastern Lake Ontario Sand Dune system. Almost 23% of the remainder of the shoreline is sand or cohesive bluffs (Type 1), most of which fall into the Type 1B category (homogeneous, sand content 20-50%). Beach type shorelines (Types 4, 5 and 6) occupy 21% (108km) of the shoreline. This includes the Eastern Lake Ontario Sand Dune system, but also a number of areas along the southern shoreline (48km) classed as coarse beaches (Type 6). Just over 10% (52km) of the shoreline falls into the low bank category (Type 3A-3C) and 7% (35km) is classed as open shoreline wetlands (Type 9), many of which are found in the northeast portion of the lake, as well as in the Braddock's Bay area near Rochester.

**Lake Ontario Shore Type Classification**  
(By Kilometer)



**Figure 9 - Lake Ontario Shore Type Classification (By Kilometer)**

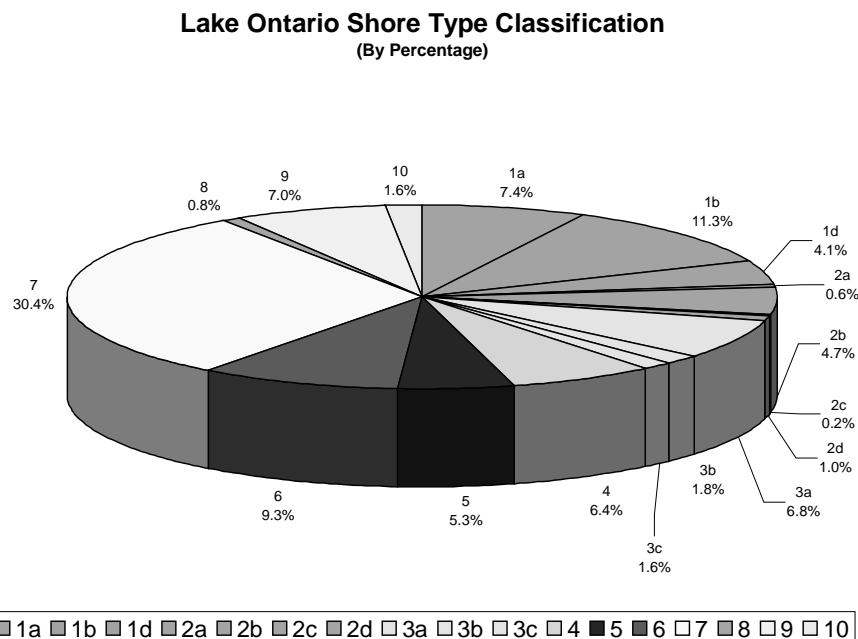


Figure 10 - Lake Ontario Shore Type Classification (By Percentage)

### 3.2.2 Shoreline Protection Classification

Table 6 presents summary statistics of the number of kilometers of each of the shoreline protection type categories found for the Lake Ontario shoreline. These are further illustrated by the histograms in Figures 11 and 12 and the pie charts illustrating the percentages in each category in Figures 13 and 14.

Table 6 - Lake Ontario Shoreline Protection Classification

Shore Protection Type	KMs of Coast
<b>1. Coastal Armoring</b>	
1A1 - Revetments >45 year lifespan	23
1A2 - Revetments 5-45 year lifespan	197
1A3 - Revetments 0-5 year lifespan	46
1A4 - Revetments 0 year lifespan (disrepair)	0



## U.S. Army Corps of Engineers - Buffalo District

1B1 - Seawalls/Bulkheads >45 year lifespan	6
1B2 - Seawalls/Bulkheads 5-45 year lifespan	153
1B3 - Seawalls/Bulkheads 0-5 year lifespan	15
1B4 - Seawalls/Bulkheads 0 year lifespan (disrepair)	0
<b>2. Beach Erosion Control Devices</b>	
2A1 - Groins >45 year lifespan	2
2A2 - Groins 5-45 year lifespan	6
2A3 - Groins 0-5 year lifespan	3
2A4 - Groins 0 year lifespan (disrepair)	0
2B1 - Jetties >45 year lifespan	17
2B2 - Jetties 5-45 year lifespan	154
2B3 - Jetties 0-5 year lifespan	2
2B4 - Jetties 0 year lifespan (disrepair)	0
2C1 - Offshore Breakwaters >45 year lifespan	4
2C2 - Offshore Breakwaters 5-45 year lifespan	2
2C3 - Offshore Breakwaters 0-5 year lifespan	1
2C4 - Offshore Breakwaters 0 year lifespan (disrepair)	0
<b>3. Non-Structural</b>	
3A1 - Beach Nourishment >45 year lifespan	2
3A2 - Beach Nourishment 5-45 year lifespan	0
3A3 - Beach Nourishment 0-5 year lifespan	0
3A4 - Beach Nourishment 0 year lifespan (disrepair)	0
3B1 - Vegetation Planting >45 year lifespan	0
3B2 - Vegetation Planting 5-45 year lifespan	0
3B3 - Vegetation Planting 0-5 year lifespan	0
3B4 - Vegetation Planting 0 year lifespan (disrepair)	0
3C1 - Slope/Bluff Stabilization >45 year lifespan	0
3C2 - Slope/Bluff Stabilization 5-45 year lifespan	3
3C3 - Slope/Bluff Stabilization 0-5 year lifespan	0
3C4 - Slope/Bluff Stabilization 0 year lifespan (disrepair)	0
<b>4. Protected Wetlands</b>	
	0
<b>5. Ad-Hoc Structures</b>	
5A1 - Concrete Rubble >45 year lifespan	0
5A2 - Concrete Rubble 5-45 year lifespan	4
5A3 - Concrete Rubble 0-5 year lifespan	41



## U.S. Army Corps of Engineers - Buffalo District

5A4 - Concrete Rubble 0 year lifespan (disrepair)	0
5B1 - Other Materials >45 year lifespan	0
5B2 - Other Materials 5-45 year lifespan	0
5B3 - Other Materials 0-5 year lifespan	6
5B4 - Other Materials 0 year lifespan (disrepair)	0
<b>6 - Unclassified</b>	0
<b>7 - No Protection</b>	180
<b>Grand Total*</b>	<b>867</b>

\*Note: More than one shore type was recorded for each kilometer reach in some cases along the shoreline. As a result the total kilometers for shore protection add up to more than the total length of the Lake Ontario shoreline.

### Lake Ontario Summary Shore Protection Classification (By Kilometer)

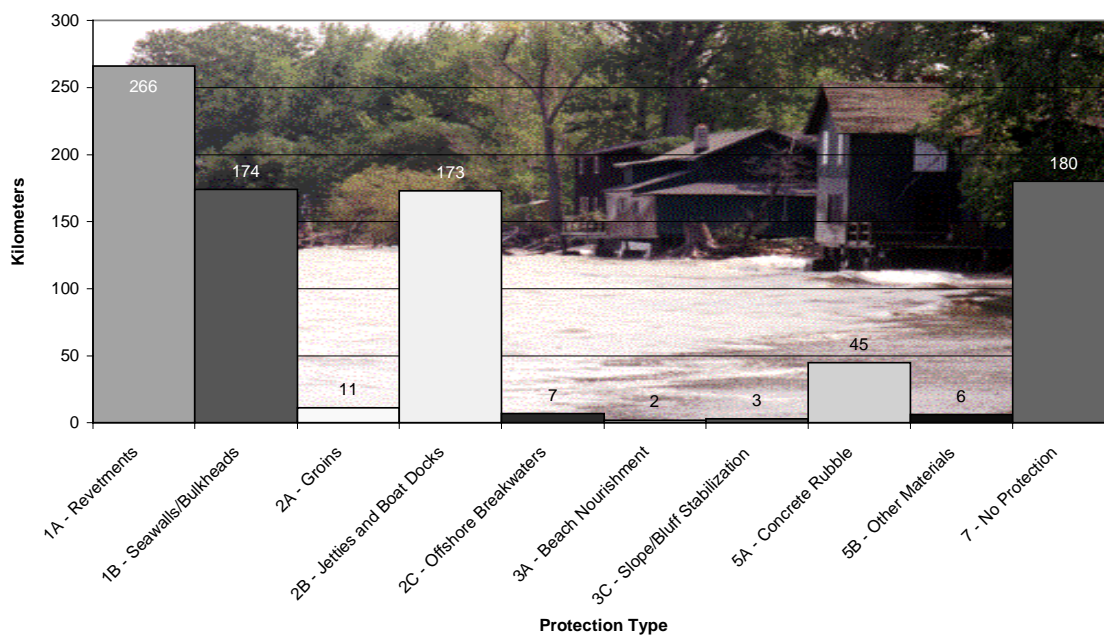


Figure 11 - Lake Ontario Shore Protection Summary (By Kilometer)

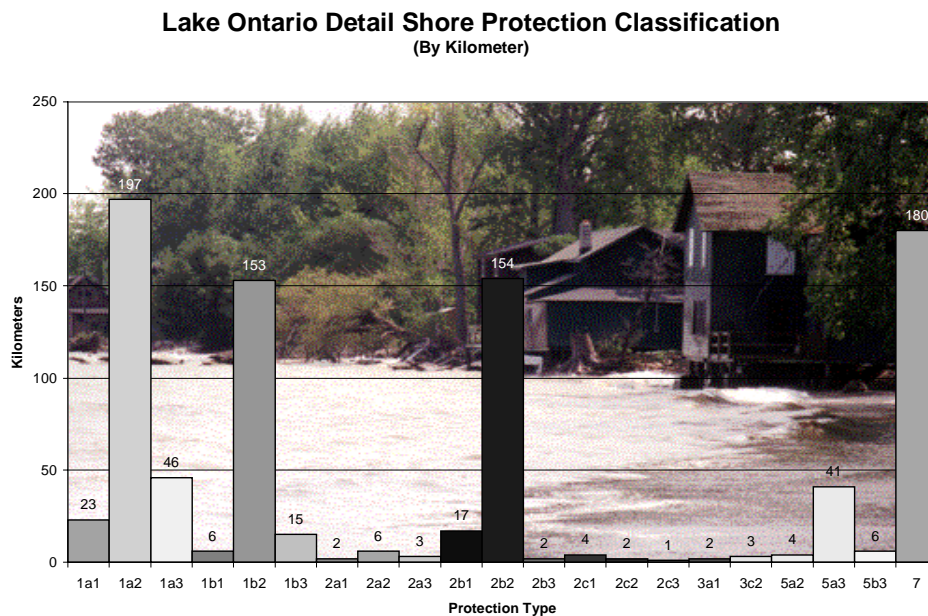


Figure 12 - Lake Ontario Shore Protection Detail (By Kilometer)

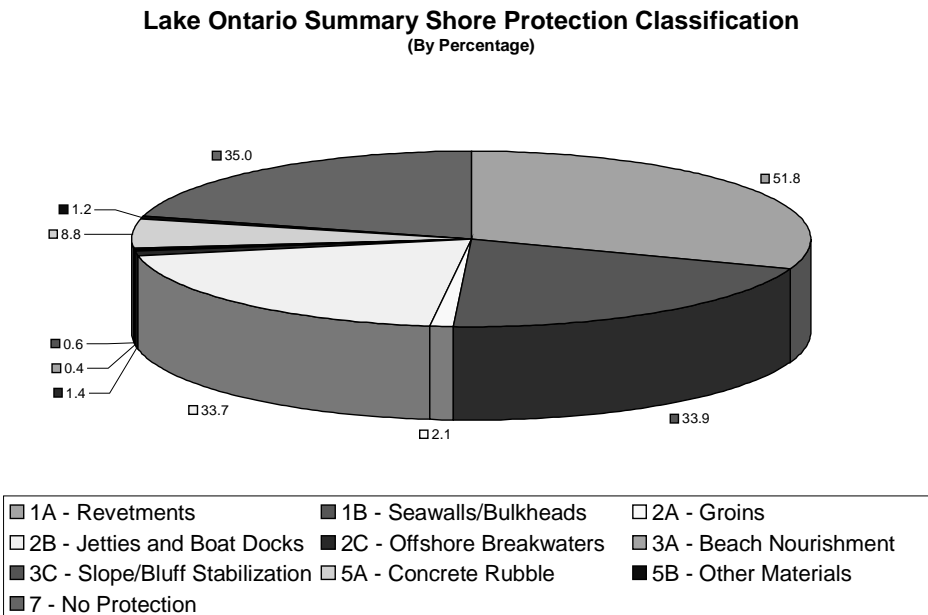


Figure 13 - Lake Ontario Shore Protection Summary (By Percentage)

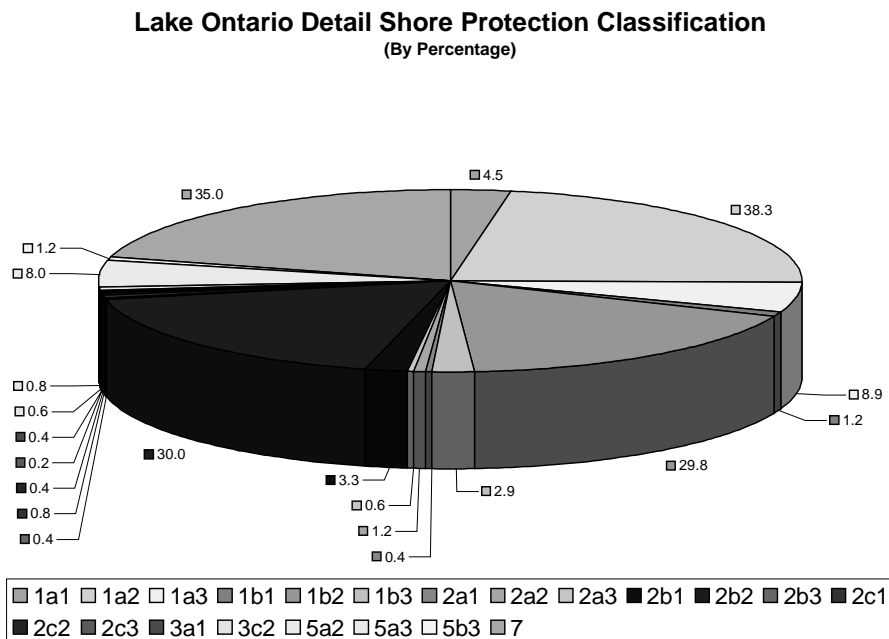


Figure 14 - Lake Ontario Shore Protection Detail (By Percentage)

Similar to Lake Erie, Lake Ontario is dominated by the presence of revetments and seawalls (Types 1A and 1B), most of which fall into the medium quality classes (1A2, 1A3, 1B2, 1B3) and represent private property protection efforts. Medium quality revetments (1A2) were the most dominant, occurring in 197 of the 514 reaches on the lake (38% of the entire shoreline). This was followed by medium quality seawalls (1B2), which were found in 153 of the 514 reaches (almost 30% of the entire shoreline). Marina boat docks and privately constructed boat docks (represented by the 2B2 class) occurred in 154 of the 514 reaches, representing coverage of 30% of the entire shoreline. Relative to Lake Erie, Lake Ontario also had more ad hoc structures noted (Types 5A and 5B). These occupied 51 of the 514 reaches, or 10% of the entire shoreline. Thirty-five percent (35%) of the Lake Ontario shoreline (180 reaches) were classified as unprotected.



### 3.2.3 Nearshore Subaqueous Classification

Table 7 presents summary statistics of the number of kilometers of each of the nearshore subaqueous type categories found for the Lake Ontario shoreline. These are further illustrated by the histogram in Figure 15 and the pie chart illustrating the percentages in each category in Figure 16.

**Table 7 - Lake Ontario Nearshore Subaqueous Classification**

Nearshore Class	Kms of Coast
<b>1. Cohesive (Till)</b>	
1A - Thick Sand Cover (>200m <sup>3</sup> /m)	0
1B - Moderate Sand Cover (50-200 m <sup>3</sup> /m)	0
1C - Thin Sand Cover (<50 m <sup>3</sup> /m)	0
<b>2. Cohesive (Lacustrine Clay)</b>	
2A - Thick Sand Cover (>200m <sup>3</sup> /m)	0
2B - Moderate Sand Cover (50-200 m <sup>3</sup> /m)	0
2C - Thin Sand Cover (<50 m <sup>3</sup> /m)	0
<b>3. Cobble/Boulder Lag Over Cohesive</b>	
3A - Thick Sand Cover (>200m <sup>3</sup> /m)	3
3B - Moderate Sand Cover (50-200 m <sup>3</sup> /m)	27
3C - Thin Sand Cover (<50 m <sup>3</sup> /m)	74
<b>4 - Sandy</b>	40
<b>5 - Bedrock (Resistant)</b>	206
<b>6 - Bedrock (Non-Resistant)</b>	164
<b>7 - Unclassified</b>	0
<b>Total</b>	<b>514</b>

The Lake Ontario nearshore zone is dominated by bedrock which comprises over 70% of the entire shoreline. Resistant bedrock (Type 5) accounts for 40% (206km) while erodible, or non-resistant bedrock (Type 6) accounts for 32% (164km). Cobble/boulder lag (Type 3A-3C) is also a significant nearshore type, with 104km (20%) falling into these categories. Sandy nearshore (Type 4) accounts for only 40 km or 8% of the entire shoreline.

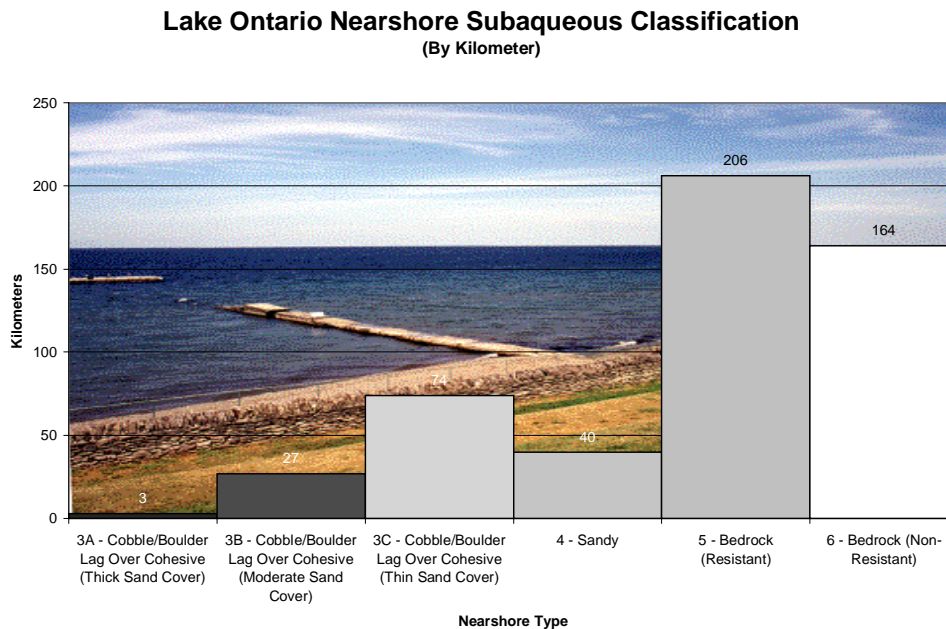


Figure 15 - Lake Ontario Nearshore Subaqueous Classification (By Kilometer)

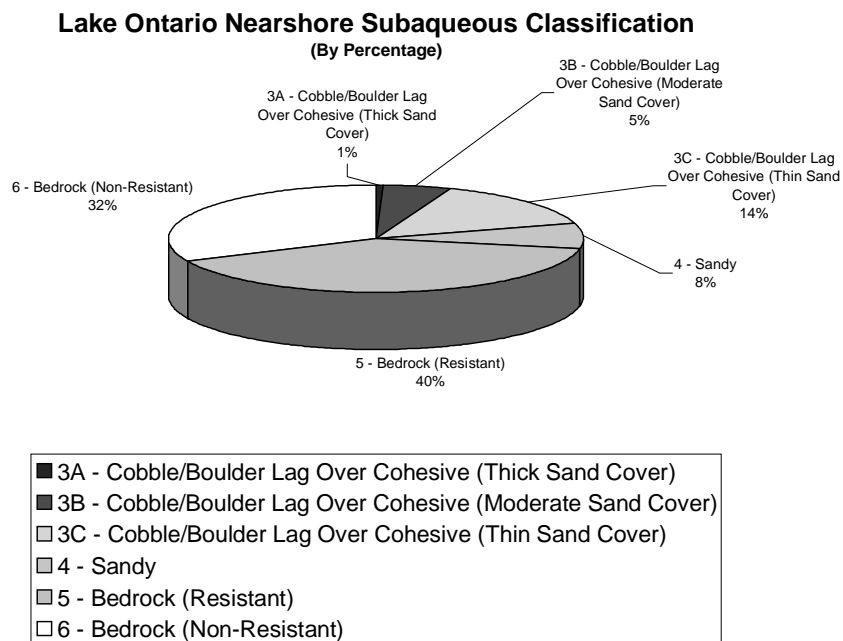


Figure 16 - Lake Ontario Nearshore Subaqueous Classification (By Percentage)



### 3.3 Niagara River

#### 3.3.1 Geomorphic Shore Type

Table 8 presents summary statistics of the number of kilometers of each of the geomorphic shore type categories found for the Niagara River shoreline. These are further illustrated by the histogram in Figure 17 and the pie chart illustrating the percentages in each category in Figure 18.

**Table 8 - Niagara River Geomorphic Shore Type Classification**

Shore Type	Km's of Coast
<b>1. Sand or Cohesive Homogeneous Bluffs</b>	
1A - Homogeneous Bluffs Sand Content 0-20%	0
1B - Homogeneous Bluffs Sand Content 20-50%	0
1C - Homogeneous Bluffs Sand Content >50%	0
1D - Composite Bluffs Sand Content 0-20%	6
1E - Composite Bluffs Sand Content 20-50%	0
1F - Composite Bluffs Sand Content >50%	0
<b>2. Sand or Cohesive Bluffs With Beach</b>	
2A - Homogeneous Bluffs Sand Content 0-20%	0
2B - Homogeneous Bluffs Sand Content 20-50%	0
2C - Homogeneous Bluffs Sand Content >50%	0
2D - Composite Bluffs Sand Content 0-20%	1
2E - Composite Bluffs Sand Content 20-50%	0
2F - Composite Bluffs Sand Content >50%	0
<b>3. Low Bank</b>	
3A - Sand Content 0-20%	0
3B - Sand Content 20-50%	22
3C - Sand Content >50%	0
<b>4 - Baymouth Barrier</b>	0
<b>5 - Sandy Beach / Dune</b>	0
<b>6 - Coarse Beaches</b>	0
<b>7 - Bedrock (Resistant)</b>	0
<b>8 - Bedrock (Non-Resistant)</b>	15



9 - Open Shoreline Wetlands	0
10 - Artificial	15
11 - Unclassified	0
Total	59

Niagara River shore types consist primarily of low bank shorelines associated with the upper portion of the river (Type 3B, 22km), the bedrock shorelines associated with the Niagara Escarpment and the Niagara Gorge (Type 8, 15km) and artificial shorelines associated with power plant installations and the City of Buffalo (Type 10, 15km). Small outcrops of composite bluffs occur in some sections (Type 1D, 6km; Type 2D, 1km).

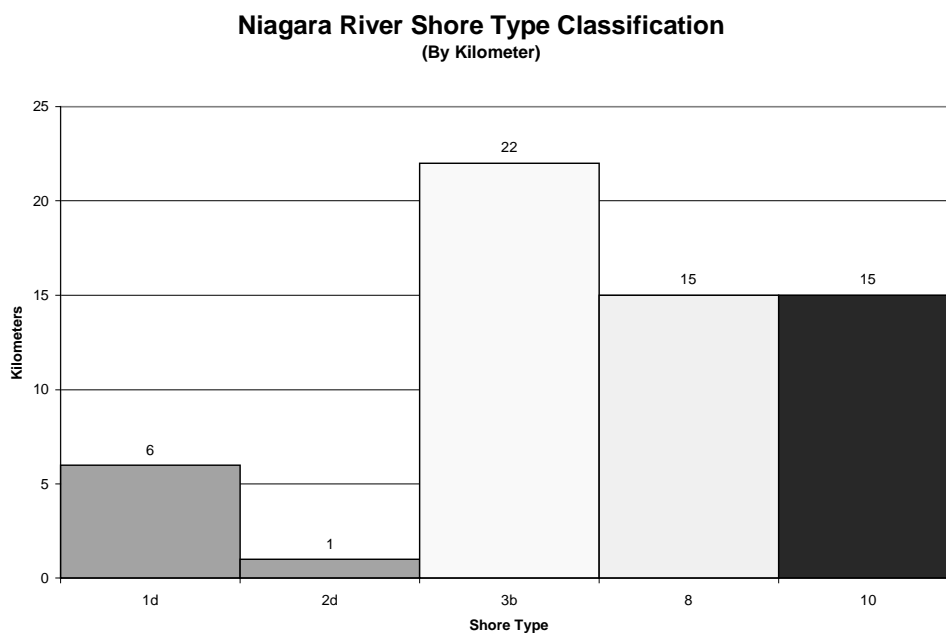


Figure 17 - Niagara River Shore Type Classification (By Kilometer)

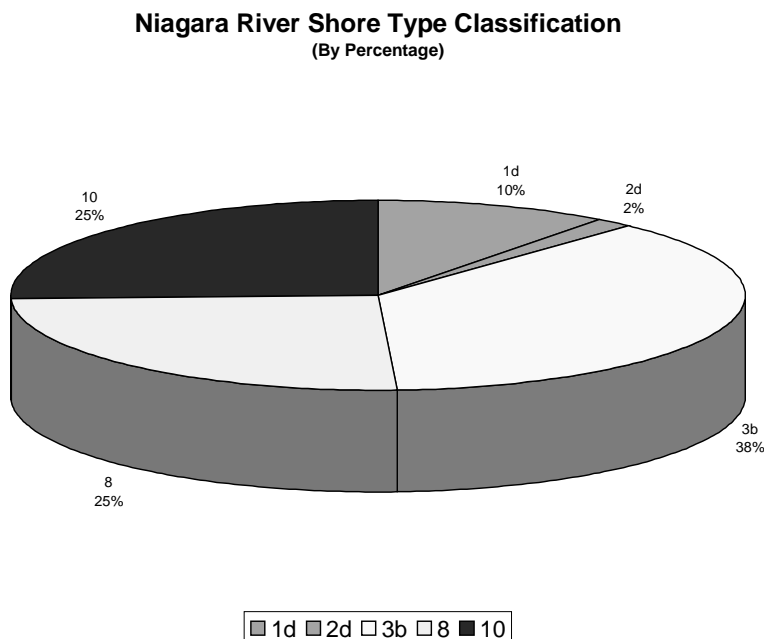


Figure 18 - Niagara River Shore Type Classification (By Percentage)

### 3.3.2 Shoreline Protection Classification

Table 9 presents summary statistics of the number of kilometers of each of the shoreline protection type categories found for the Niagara River shoreline. These are further illustrated by the histogram in Figure 19 and the pie chart illustrating the percentages in each category in Figure 20.

Table 9 - Niagara River Shoreline Protection Classification

Shore Protection Type	KMs of Coast
<b>1. Coastal Armoring</b>	
1A1 - Revetments >45 year lifespan	25
1A2 - Revetments 5-45 year lifespan	7
1A3 - Revetments 0-5 year lifespan	0
1A4 - Revetments 0 year lifespan (disrepair)	0



## U.S. Army Corps of Engineers - Buffalo District

1B1 - Seawalls/Bulkheads >45 year lifespan	21
1B2 - Seawalls/Bulkheads 5-45 year lifespan	9
1B3 - Seawalls/Bulkheads 0-5 year lifespan	0
1B4 - Seawalls/Bulkheads 0 year lifespan (disrepair)	0
<b>2. Beach Erosion Control Devices</b>	
2A1 - Groins >45 year lifespan	0
2A2 - Groins 5-45 year lifespan	0
2A3 - Groins 0-5 year lifespan	0
2A4 - Groins 0 year lifespan (disrepair)	0
2B1 - Jetties >45 year lifespan	0
2B2 - Jetties 5-45 year lifespan	15
2B3 - Jetties 0-5 year lifespan	0
2B4 - Jetties 0 year lifespan (disrepair)	0
2C1 - Offshore Breakwaters >45 year lifespan	0
2C2 - Offshore Breakwaters 5-45 year lifespan	0
2C3 - Offshore Breakwaters 0-5 year lifespan	0
2C4 - Offshore Breakwaters 0 year lifespan (disrepair)	0
<b>3. Non-Structural</b>	
3A1 - Beach Nourishment >45 year lifespan	0
3A2 - Beach Nourishment 5-45 year lifespan	0
3A3 - Beach Nourishment 0-5 year lifespan	0
3A4 - Beach Nourishment 0 year lifespan (disrepair)	0
3B1 - Vegetation Planting >45 year lifespan	0
3B2 - Vegetation Planting 5-45 year lifespan	0
3B3 - Vegetation Planting 0-5 year lifespan	0
3B4 - Vegetation Planting 0 year lifespan (disrepair)	0
3C1 - Slope/Bluff Stabilization >45 year lifespan	0
3C2 - Slope/Bluff Stabilization 5-45 year lifespan	0
3C3 - Slope/Bluff Stabilization 0-5 year lifespan	0
3C4 - Slope/Bluff Stabilization 0 year lifespan (disrepair)	0
<b>4. Protected Wetlands</b>	
	0
<b>5. Ad-Hoc Structures</b>	
5A1 - Concrete Rubble >45 year lifespan	0
5A2 - Concrete Rubble 5-45 year lifespan	0
5A3 - Concrete Rubble 0-5 year lifespan	0

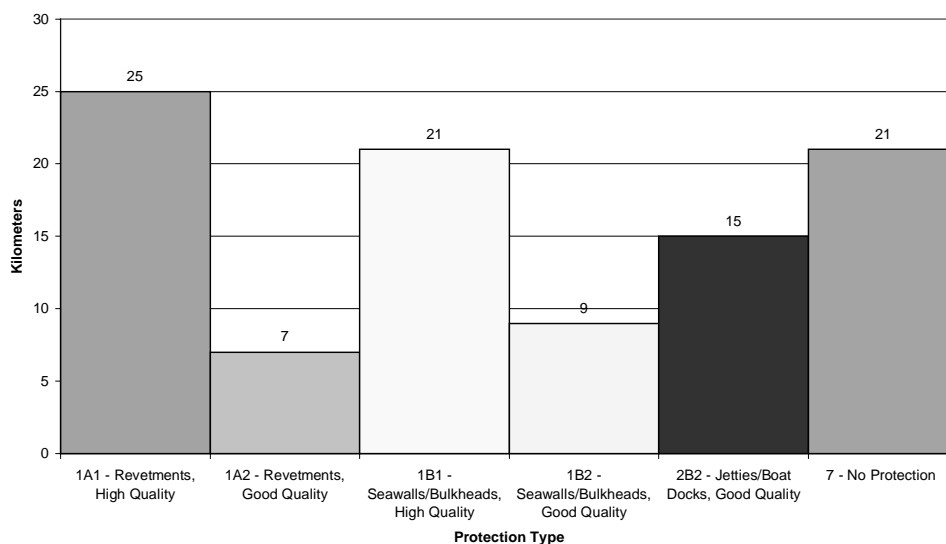


## U.S. Army Corps of Engineers - Buffalo District

5A4 - Concrete Rubble 0 year lifespan (disrepair)	0
5B1 - Other Materials >45 year lifespan	0
5B2 - Other Materials 5-45 year lifespan	0
5B3 - Other Materials 0-5 year lifespan	0
5B4 - Other Materials 0 year lifespan (disrepair)	0
<b>6 - Unclassified</b>	0
<b>7 - No Protection</b>	21
<b>Grand Total*</b>	98

\*Note: More than one shore type was recorded for each kilometer reach in some cases along the shoreline. As a result the total kilometers for shore protection add up to more than the total length of the Niagara River shoreline.

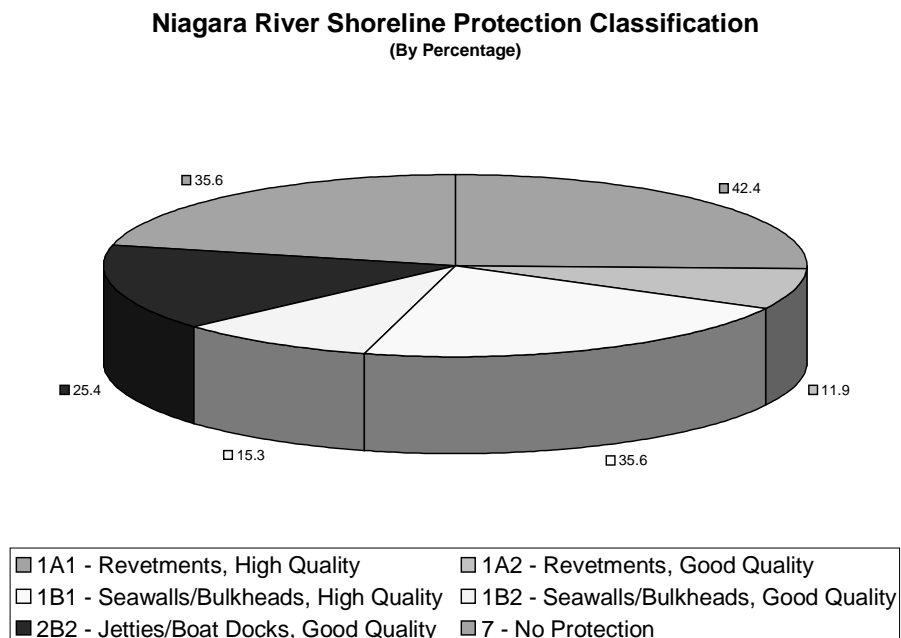
**Niagara River Shoreline Protection Classification**  
(By Kilometer)



**Figure 19 - Niagara River Shoreline Protection (By Kilometer)**



Most of the shore protection in the Niagara River is concentrated along the City of Buffalo riverfront and consists primarily of revetments (Type 1A) and seawalls (Type 1B) of high quality (1A1, 25km; 1B1, 21km). A number of marina structures and private boat docks were also noted in 15 reaches of shoreline (25%). Twenty-one (21) kilometers of the river were classed as unprotected (Type 7).



**Figure 20 - Niagara River Shoreline Protection (By Percentage)**

### 3.3.3 Nearshore Subaqueous Classification

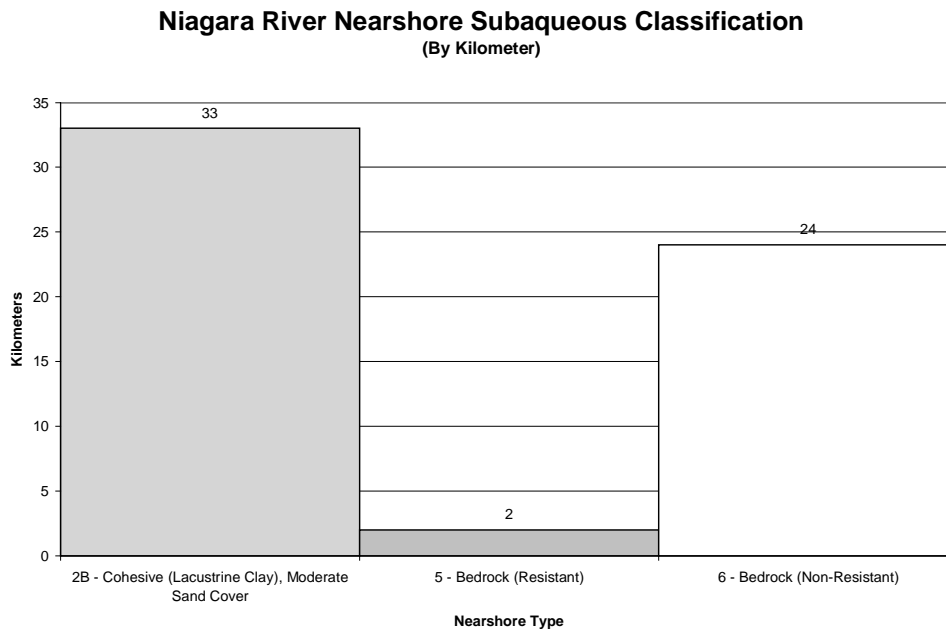
Table 10 presents summary statistics of the number of kilometers of each of the nearshore subaqueous type categories found for the Niagara River shoreline. These are further illustrated by the histogram in Figure 21 and the pie chart illustrating the percentages in each category in Figure 22.



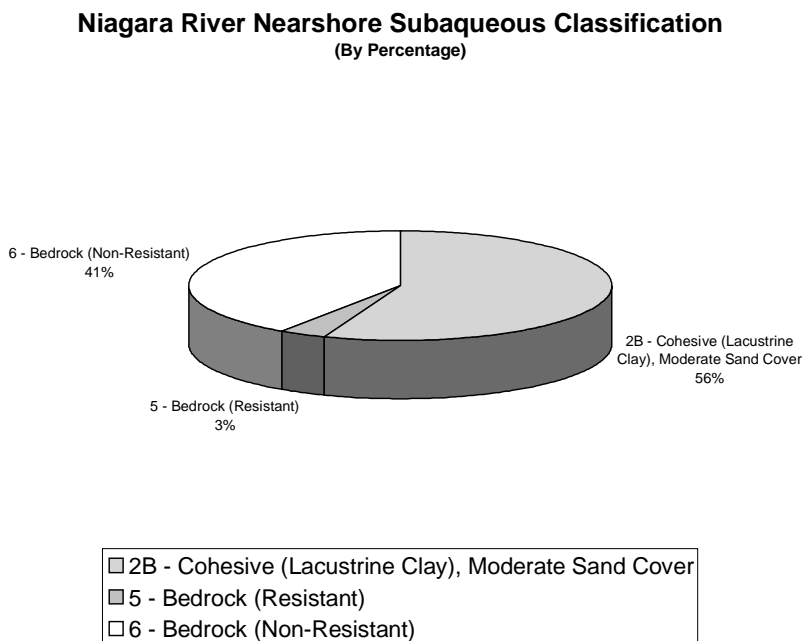
Two simple distinctions appear in the data. Cohesive lacustrine clays, with moderate sand cover (Type 2B) dominate the upper portion of the river (33km, 56%), while non-resistant bedrock (Type 6) associated with the Niagara Gorge dominates the lower portion of the river to Lake Ontario (24km, 41%).

**Table 10 - Niagara River Nearshore Subaqueous Classification**

Nearshore Class	Kms of Coast
<b>1. Cohesive (Till)</b>	
1A - Thick Sand Cover (>200m <sup>3</sup> /m)	0
1B - Moderate Sand Cover (50-200 m <sup>3</sup> /m)	0
1C - Thin Sand Cover (<50 m <sup>3</sup> /m)	0
<b>2. Cohesive (Lacustrine Clay)</b>	
2A - Thick Sand Cover (>200m <sup>3</sup> /m)	0
2B - Moderate Sand Cover (50-200 m <sup>3</sup> /m)	33
2C - Thin Sand Cover (<50 m <sup>3</sup> /m)	0
<b>3. Cobble/Boulder Lag Over Cohesive</b>	0
3A - Thick Sand Cover (>200m <sup>3</sup> /m)	0
3B - Moderate Sand Cover (50-200 m <sup>3</sup> /m)	0
3C - Thin Sand Cover (<50 m <sup>3</sup> /m)	0
<b>4 - Sandy</b>	0
<b>5 - Bedrock (Resistant)</b>	2
<b>6 - Bedrock (Non-Resistant)</b>	24
<b>7 - Unclassified</b>	0
Total	59



**Figure 21 - Niagara River Nearshore Subaqueous Classification (By Kilometer)**



**Figure 22 - Niagara River Nearshore Subaqueous Classification (By Percentage)**



### 3.4 St. Lawrence River

#### 3.4.1 Geomorphic Shore Type

Table 11 presents summary statistics of the number of kilometers of each of the geomorphic shore type categories found for the St. Lawrence River shoreline. These are further illustrated by the histogram in Figure 23 and the pie chart illustrating the percentages in each category in Figure 24.

**Table 11 - St. Lawrence River Geomorphic Shore Type Classification**

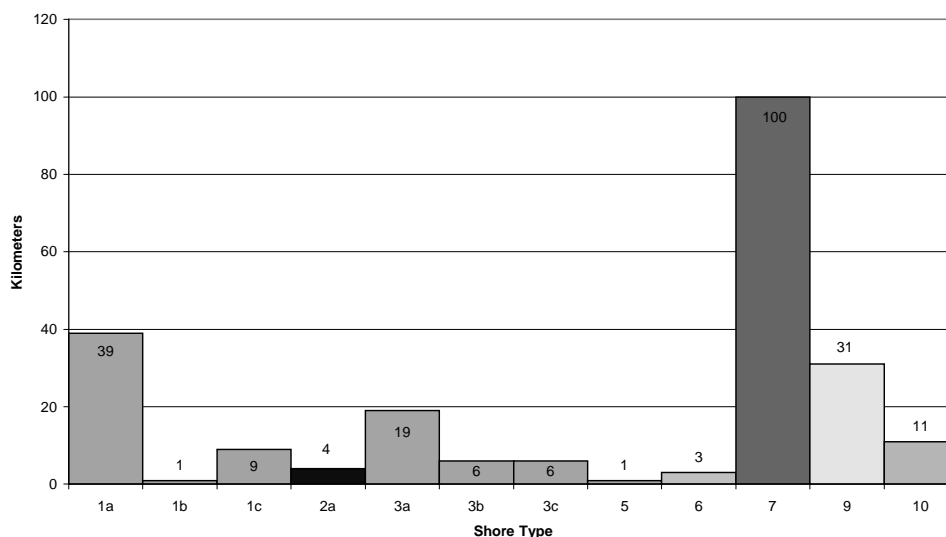
Shore Type	Km's of Coast
<b>1. Sand or Cohesive Homogeneous Bluffs</b>	
1A - Homogeneous Bluffs Sand Content 0-20%	39
1B - Homogeneous Bluffs Sand Content 20-50%	1
1C - Homogeneous Bluffs Sand Content >50%	9
1D - Composite Bluffs Sand Content 0-20%	0
1E - Composite Bluffs Sand Content 20-50%	0
1F - Composite Bluffs Sand Content >50%	0
<b>2. Sand or Cohesive Bluffs With Beach</b>	
2A - Homogeneous Bluffs Sand Content 0-20%	4
2B - Homogeneous Bluffs Sand Content 20-50%	0
2C - Homogeneous Bluffs Sand Content >50%	0
2D - Composite Bluffs Sand Content 0-20%	0
2E - Composite Bluffs Sand Content 20-50%	0
2F - Composite Bluffs Sand Content >50%	0
<b>3. Low Bank</b>	
3A - Sand Content 0-20%	19
3B - Sand Content 20-50%	6
3C - Sand Content >50%	6
<b>4 - Baymouth Barrier</b>	0
<b>5 - Sandy Beach / Dune</b>	1
<b>6 - Coarse Beaches</b>	3
<b>7 - Bedrock (Resistant)</b>	100
<b>8 - Bedrock (Non-Resistant)</b>	0



9 - Open Shoreline Wetlands	31
10 - Artificial	11
11 - Unclassified	0
Total	230

The St. Lawrence River is dominated by resistant bedrock shore types (Type 7) (100km, ~44%), the majority of which occur in the "Thousand Island" reaches of the river closest to Lake Ontario. Over 21% (49km) of the shore is classed as sand or cohesive bluff (Type 1), most of which (39km) is homogenous with sand content from 0-20% (Type 1A). Low bank (Type 3) and open shoreline wetland categories are also important, occupying just over 13% each of the total shoreline.

**St. Lawrence River Shore Type Classification  
(By Total Km)**



**Figure 23 - St. Lawrence River Shore Type Classification (By Kilometer)**

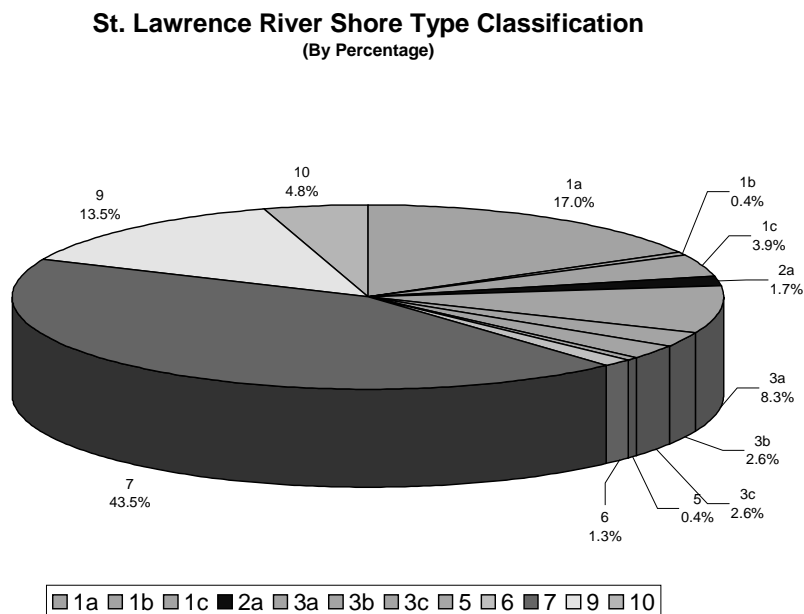


Figure 24 - St. Lawrence River Shore Type Classification (By Percentage)

### 3.4.2 Shoreline Protection Classification

Table 12 presents summary statistics of the number of kilometers of each of the shoreline protection type categories found for the St. Lawrence River shoreline. These are further illustrated by the histograms in Figure 25 and 26 and the pie charts illustrating the percentages in each category in Figures 27 and 28.

Table 12 - St. Lawrence River Shoreline Protection Classification

Shore Protection Type	KMs of Coast
<b>1. Coastal Armoring</b>	
1A1 - Revetments >45 year lifespan	22
1A2 - Revetments 5-45 year lifespan	75
1A3 - Revetments 0-5 year lifespan	0
1A4 - Revetments 0 year lifespan (disrepair)	0



## U.S. Army Corps of Engineers - Buffalo District

1B1 - Seawalls/Bulkheads >45 year lifespan	8
1B2 - Seawalls/Bulkheads 5-45 year lifespan	75
1B3 - Seawalls/Bulkheads 0-5 year lifespan	1
1B4 - Seawalls/Bulkheads 0 year lifespan (disrepair)	0
<b>2. Beach Erosion Control Devices</b>	
2A1 - Groins >45 year lifespan	0
2A2 - Groins 5-45 year lifespan	0
2A3 - Groins 0-5 year lifespan	0
2A4 - Groins 0 year lifespan (disrepair)	0
2B1 - Jetties >45 year lifespan	6
2B2 - Jetties 5-45 year lifespan	100
2B3 - Jetties 0-5 year lifespan	0
2B4 - Jetties 0 year lifespan (disrepair)	0
2C1 - Offshore Breakwaters >45 year lifespan	1
2C2 - Offshore Breakwaters 5-45 year lifespan	1
2C3 - Offshore Breakwaters 0-5 year lifespan	0
2C4 - Offshore Breakwaters 0 year lifespan (disrepair)	0
<b>3. Non-Structural</b>	
3A1 - Beach Nourishment >45 year lifespan	0
3A2 - Beach Nourishment 5-45 year lifespan	0
3A3 - Beach Nourishment 0-5 year lifespan	0
3A4 - Beach Nourishment 0 year lifespan (disrepair)	0
3B1 - Vegetation Planting >45 year lifespan	0
3B2 - Vegetation Planting 5-45 year lifespan	0
3B3 - Vegetation Planting 0-5 year lifespan	0
3B4 - Vegetation Planting 0 year lifespan (disrepair)	0
3C1 - Slope/Bluff Stabilization >45 year lifespan	0
3C2 - Slope/Bluff Stabilization 5-45 year lifespan	0
3C3 - Slope/Bluff Stabilization 0-5 year lifespan	0
3C4 - Slope/Bluff Stabilization 0 year lifespan (disrepair)	0
<b>4. Protected Wetlands</b>	
	0
<b>5. Ad-Hoc Structures</b>	
5A1 - Concrete Rubble >45 year lifespan	0
5A2 - Concrete Rubble 5-45 year lifespan	0
5A3 - Concrete Rubble 0-5 year lifespan	0

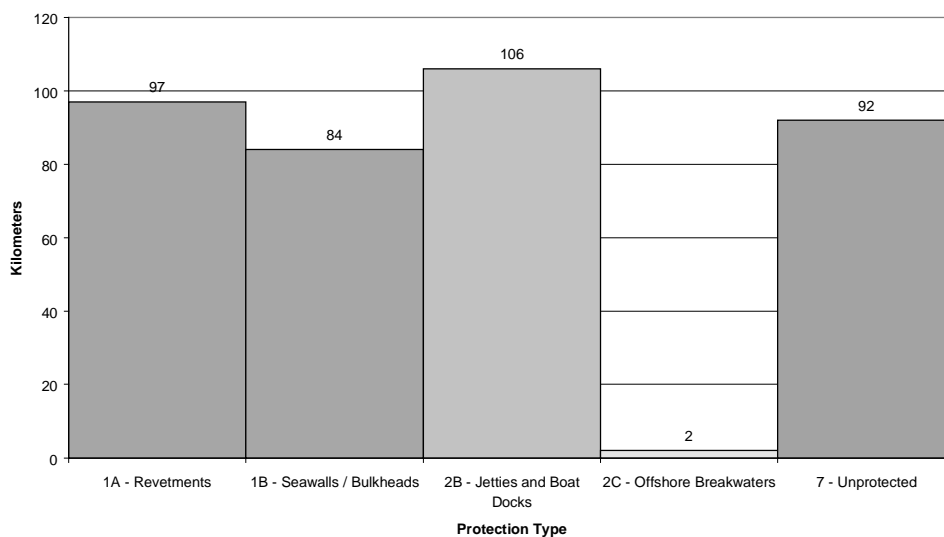


## U.S. Army Corps of Engineers - Buffalo District

5A4 - Concrete Rubble 0 year lifespan (disrepair)	0
5B1 - Other Materials >45 year lifespan	0
5B2 - Other Materials 5-45 year lifespan	0
5B3 - Other Materials 0-5 year lifespan	0
5B4 - Other Materials 0 year lifespan (disrepair)	0
<b>6 - Unclassified</b>	0
<b>7 - No Protection</b>	92
<b>Grand Total*</b>	<b>381</b>

\*Note: More than one shore type was recorded for each kilometer reach in some cases along the shoreline. As a result the total kilometers for shore protection add up to more than the total length of the St. Lawrence River shoreline.

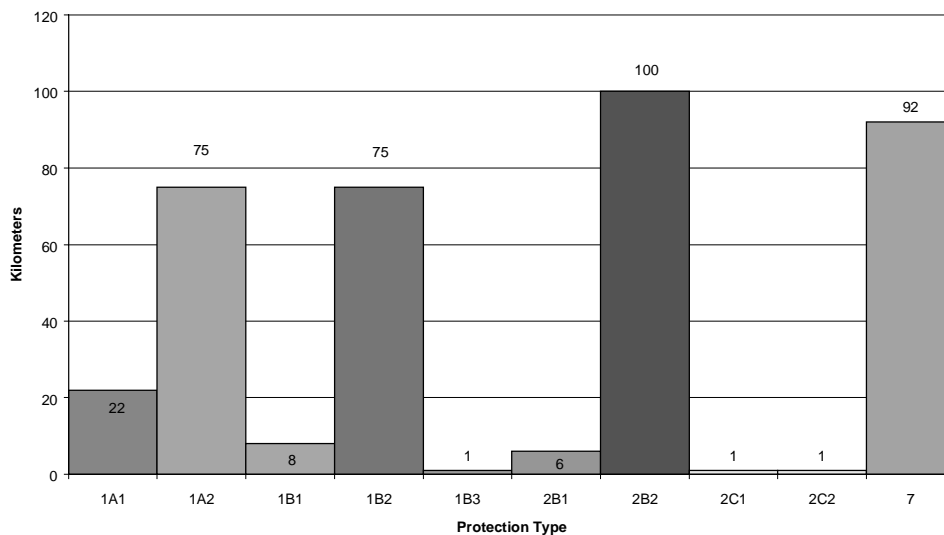
**St. Lawrence River Summary Shore Protection Classification**  
(By Kilometer)



**Figure 25 - St. Lawrence River Shore Protection Summary (By Kilometer)**

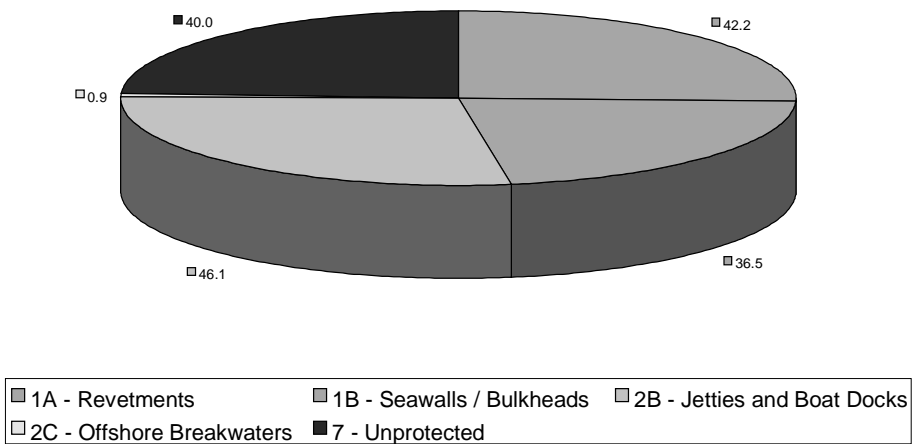


**St. Lawrence River Detailed Shore Protection Classification**  
(By Kilometer)



**Figure 26 - St. Lawrence River Shore Protection Detail (By Kilometer)**

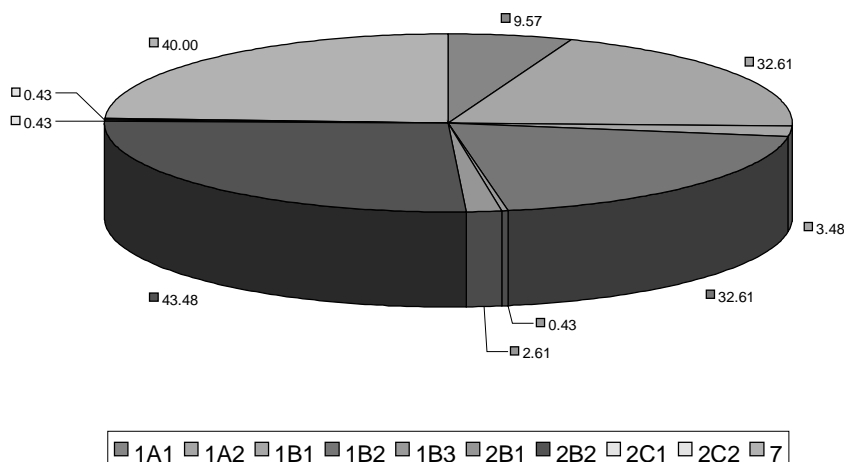
**St. Lawrence River Summary Shore Protection Classification**  
(By Percentage)



**Figure 27 - St. Lawrence River Shore Protection Summary (By Percentage)**



**St. Lawrence River Detailed Shore Protection Classification**  
(By Percent)



**Figure 28 - St. Lawrence River Shore Protection Detail (By Percentage)**

Shore protection in the St. Lawrence River is relatively evenly distributed between 4 main categories. Jetties and boat docks (Type 2B) were found in 106 of the 230 reaches representing 46% of the shoreline. Of these the majority (100 reaches) were Type 2B2 and represent the multitude of private boat docks and marina facilities found along the shoreline. The second major category was revetments (Type 1A) which were found in 97 of the 230 reaches (42%). This was followed closely by seawalls and bulkheads (Type 1B) which were found in 84 of the 230 reaches (36%). The majority of the revetments and seawalls were of medium quality (i.e., 1A2 and 1B2). Finally, 40% of the St. Lawrence River shoreline (92km) was classed as unprotected (Type 7).

### 3.4.3 Nearshore Subaqueous Classification

Table 13 presents summary statistics of the number of kilometers of each of the nearshore subaqueous type categories found for the St. Lawrence River shoreline. These are further illustrated by the histogram in Figure 29 and the pie chart illustrating the percentages in each category in Figure 30.



**Table 13 - St. Lawrence River Nearshore Subaqueous Classification**

<b>Nearshore Class</b>	<b>Kms of Coast</b>
<b>1. Cohesive (Till)</b>	
1A - Thick Sand Cover (>200m <sup>3</sup> /m)	9
1B - Moderate Sand Cover (50-200 m <sup>3</sup> /m)	0
1C - Thin Sand Cover (<50 m <sup>3</sup> /m)	29
<b>2. Cohesive (Lacustrine Clay)</b>	
2A - Thick Sand Cover (>200m <sup>3</sup> /m)	0
2B - Moderate Sand Cover (50-200 m <sup>3</sup> /m)	0
2C - Thin Sand Cover (<50 m <sup>3</sup> /m)	64
<b>3. Cobble/Boulder Lag Over Cohesive</b>	
3A - Thick Sand Cover (>200m <sup>3</sup> /m)	0
3B - Moderate Sand Cover (50-200 m <sup>3</sup> /m)	0
3C - Thin Sand Cover (<50 m <sup>3</sup> /m)	1
<b>4 - Sandy</b>	6
<b>5 - Bedrock (Resistant)</b>	121
<b>6 - Bedrock (Non-Resistant)</b>	0
<b>7 - Unclassified</b>	0
<b>Total</b>	<b>230</b>

The nearshore zone of the St. Lawrence River is dominated by resistant bedrock (Type 5) which occurs over 52% of the shoreline (121km), mainly in the upper portion of the river closest to Lake Ontario (Thousand Islands region). Cohesive lacustrine clays, with a thin sand cover (Type 2C) occur in 64km, representing 28% of the shoreline. Cohesive tills (Type 1A, 9km; Type 1C, 29km) and sand (Type 4, 6km) effectively make up the remainder of the shoreline.

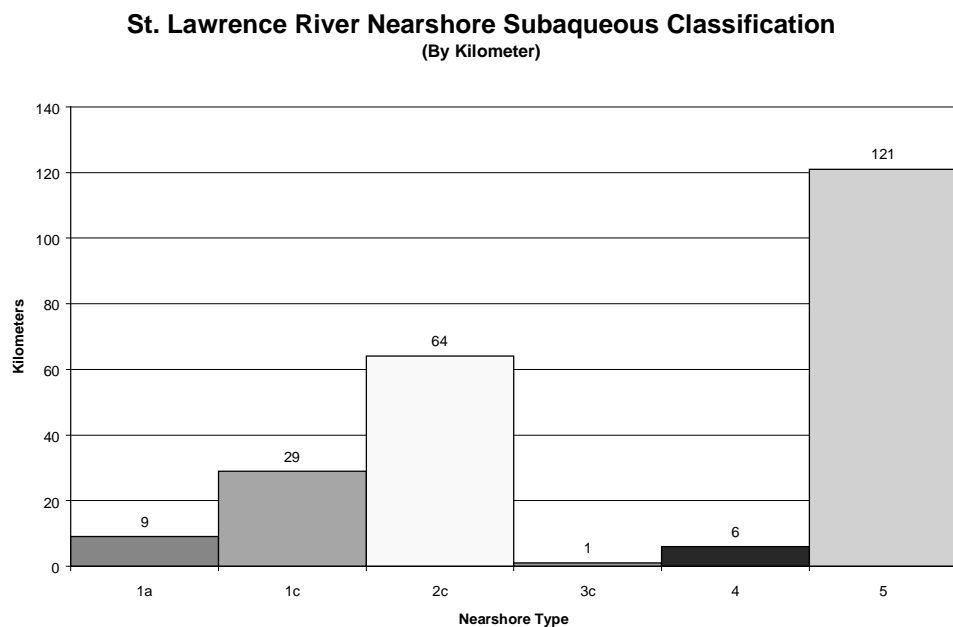


Figure 29 - St. Lawrence River Nearshore Subaqueous Classification (By Kilometer)

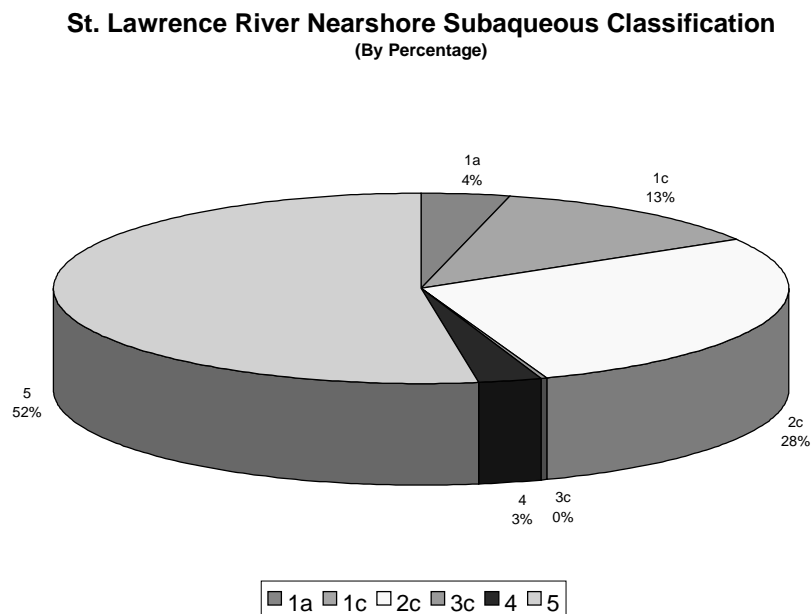


Figure 30 - St. Lawrence River Nearshore Subaqueous Classification (By Percentage)



## 4.0 Discussion and Recommendations for Future Refinements

### 4.1 General

Reclassification of the Lakes Erie and Ontario shoreline and the shoreline of the Niagara and St. Lawrence River has accomplished a number of important things:

1. The level and comprehensiveness of the classification has greatly added to our knowledge of these shorelines, particularly with reference to the level of detail regarding shore type and nearshore geology. This provides an excellent baseline data set for future studies of these shorelines.
2. A number of inconsistencies present in the original IJC classification of the Lake Erie and Ontario shorelines have been corrected or minimized. In addition, more detail has been added. This has resulted in a more accurate classification of these areas.
3. There is now a more accurate base level of shore classification information available for the Niagara and St. Lawrence Rivers - something that was available only in a limited fashion as a result of the IJC Classification.
4. Data for these shorelines is now consistent with similar shore classification data produced for Lake Michigan in the LMPDS. This means that there is now a comprehensive "3-Lake" database of shore classification and other information, which can serve as a starting point for any future Great Lakes "basin-wide" studies, at least for U.S. shorelines.
5. Although it is just a "snapshot" of April 1999 conditions, there is now a much better grasp on the types, quality *and* extent of shore protection structures in place around the lakes and along the rivers. The video tape obtained by USACE Buffalo was a extremely useful tool in determining this. It is recommended that such an activity be carried out on a regular basis (perhaps every 3-5 years), so as to monitor and document any major changes that take place along the shoreline.

### 4.2 Potential Future Refinements

While the Shoreline Classification system and it's associated application to the Lake Erie and Ontario shoreline and the Niagara and St. Lawrence Rivers has undergone substantial refinement and improvement from the original scheme developed for the IJC Reference



Study, it is likely that a number of additional improvements may be required as a result of ongoing activities within the Lower Great Lakes Erosion Study, as well as potential other activities that may be carried out on Lake Ontario by the IJC. This includes the following issues:

- The reclassification of the Erie and Ontario shorelines, combined with various field visits by the LGLES team, identified a number of erodible, or "non-resistant" bedrock shorelines, as well as a number of shorelines where erodible bedrock was exposed at and slightly above the waterline, but was then overlain by tills in the remainder of the bluff face. This leads to a potential problem in accurately capturing these types of shorelines in the classification system. This has been highlighted by Nairn in his review of site study areas (Baird & Associates, 1999):

*"Two interesting issues arise in the designation of a geomorphic or backshore class for the prevalent shale (non-resistant bedrock) shore type on Lakes Erie and Ontario. The sand content qualifier to the bluff type was meant to provide information necessary to complete a sediment budget. Therefore, for shale bluffs [classified as Type 8 bedrock (non-resistant)], where all of the eroded material remains in the nearshore zone, the "sand content" should effectively be 100% (notwithstanding the fact that this material breaks down in size with time). Where till overlies shale in the bluff face, a composite bluff face designation may appear appropriate. However, the purpose of the composite designation was to help highlight areas that may be susceptible to deep seated slope failures, therefore, a composite bluff designation would be misleading in these cases. There are two options to address these potential inconsistencies/shortcomings with the geomorphic classification tier as it applies to eroding shale bluffs:*

- 1) Add two geomorphic classes: homogeneous shale bluff and composite (till or cohesive sediment over shale);*
- 2) Add another data field in the reach data base consisting of the average elevation of the top of the bedrock.*

*We would propose that Option 2 would provide the most additional information and therefore, provide the greatest value for the time invested in entering the available information. In areas where bedrock exists at a depth which does not influence shoreline erosion (say depths of 10 m or more), a consistent designation could be applied (e.g. simply >10 m). This information is available for all of the Ohio shoreline in a draft map format from ODNR, but would have to be estimated for the Pennsylvania and New York shorelines.*



- Additional quality control / assurance review of the lakewide data base will likely be required should USACE Buffalo proceed with the conduction of site specific field investigations and the lakewide application of the Flood and Erosion Prediction System being developed by Baird & Associates. Information gathered through a more detailed investigation and data collection program at a number of sites under consideration will effectively assist in "ground-truthing" the classification data, particularly data on nearshore geology. Any changes required can then be incorporated for these areas.
- Discussions are currently underway with both the IJC and Environment Canada to conduct similar reclassifications for the Canadian shoreline of Lake Ontario and the St. Lawrence River for possible use in evaluating new water level regulation criteria for these waterbodies. It may be possible that the shore classes in the present scheme do not account for all shore types present on the Canadian shoreline. Additionally, both the data and the database formats will need to be consistent. As such, minor revisions may be required to address this.

### 4.3 Recommendations

USACE Buffalo should continue with the conduction of site specific studies along Lake Erie and Ontario (and possibly the St. Lawrence River), as well as the eventual development of the Flood and Erosion Prediction System for these areas. This will add more detail to the classification and provide "ground truthing" of some of the data in the site specific areas.

Staff of USACE Buffalo should continue to lobby both the IJC and their Canadian counterparts at Environment Canada for the development of similar databases for the Canadian shorelines of Lake Ontario and the St. Lawrence River. This would be a huge step in the development of the first, comprehensive, integrated, "bi-national" database for these waterbodies, as well as provide significant baseline information for the ultimate evaluation of shoreline impacts as a result of changes to Lake Ontario regulation practices.

The helicopter survey and resulting video-tape obtained by USACE Buffalo for use in this classification exercise proved invaluable in obtaining better detail on the nature of the shoreline, particularly the extent and types of shore protection structures present. It also helped in confirming the shore type in areas where this was difficult to determine from the air photos. It is recommended that USACE Buffalo attempt to conduct similar



aerial surveys on a regular basis (perhaps every 3-5 years). The information on the video is, in many cases, as good if not better than that from air photos, and the cost for acquiring the data is certainly less, particularly if use of US Coast Guard helicopters can be arranged.

## REFERENCES

- Baird & Associates, 1998. New York Power Authority St. Lawrence - FDR Power Project (FERC No. 2000) - Shoreline Erosion and Sedimentation Assessment Study, Draft Final Report.
- Baird & Associates, 1999(Draft). Overview of Study Sites and Design of Field Program - Lower Great Lakes Erosion Study. Consulting Report prepared for the U.S. Army Corps of Engineers - Buffalo District, 13pp., plus Appendices.
- Benson, J., 1978. Lake Erie Shore Erosion and Flooding, Lucas County, Ohio. State of Ohio Department of Natural Resources, Division of Geological Survey, Report of Investigations No. 107, 99pp.
- Brennan, S.F., and Calkin, P.E., 1984. Great Lakes Coastal Geology - Analysis of Bluff Erosion Along the Southern Coastline of Lake Ontario, New York. New York Sea Grant Institute, Albany, New York, 74pp.
- Calkin, P.E., and Muller, E.H., 1992. Pleistocene Stratigraphy of the Erie and Ontario Lake Bluffs in New York. In: Quaternary Coasts of the United States: Marine and Lacustrine Systems, Society for Sedimentary Geology (SEPM) Special Publication No.48, p.385-396.
- Calkin, P.E., Muller, E.H., and Drexhage, T.F., 1982. Quaternary Stratigraphy and Bluff Erosion, Western Lake Ontario, New York. In: Buehler, E.J., and Calkin, P.E. (eds.), Geology of the Northern Appalachian Basin, Western New York: Field Trip Guidebooks for New York State Geological Association, 54<sup>th</sup> Annual Meeting, Amherst, N.Y., p.285-323.
- Carter, C.H., 1976. Lake Erie Shore Erosion, Lake County, Ohio: Setting, Processes and Recession Rates From 1876 to 1973. State of Ohio Department of Natural Resources, Division of Geological Survey, Report of Investigations No. 99, 105pp.



- Carter, C.H., and Guy, D.E., 1980. Lake Erie Shore Erosion and Flooding, Erie and Sandusky Counties, Ohio: Setting, Processes and Recession Rates From 1877 to 1973. State of Ohio Department of Natural Resources, Division of Geological Survey, Report of Investigations No. 115, 130pp.
- Carter, C.H., and Guy, D.E., 1983. Lake Erie Shore Erosion, Ashtabula County, Ohio: Setting, Processes and Recession Rates From 1876 to 1973. State of Ohio Department of Natural Resources, Division of Geological Survey, Report of Investigations No. 122, 107pp.
- Environment Canada and United States Coast Guard, 1994. Environmental Sensitivity Atlas for the St. Lawrence River Shorelines. Environment Canada Environmental Protection Branch - Ontario Region, 52pp. Including Maps.
- Fuller, J.A., and Foster, D.S., 1998. Sidescan Sonar Differentiation of Ohio's Nearshore (Lake Erie) Surficial Sediments. State of Ohio Department of Natural Resources Division of Geological Survey, Digital Chart and Map Series Number 23.
- Geier, R.J., and Calkin, P.E., 1983. Great Lakes Coastal Geology - Stratigraphy and Bluff Recession Along the Lake Erie Coast, New York. New York Sea Grant Institute, Albany, New York, 58pp.
- Gillette, T.G., and Dollen, B.H., 1940. Geology of the Clyde and Sodus Bay Quadrangles, New York. New York State Museum Bulletin, No.320, 179pp.
- Guy, D.E., 1997. Lake Erie Sixty-Year Erosion Hazard Area in Lake County, Ohio. ODNr Report Prepared for Federal Emergency Management Agency Contract EMW-96-CA-0080, 33pp.
- Guy, D.E., Benson, D.J. and Carter, C.H., 1997a. Lake Erie Shore Erosion and Flooding, Cuyahoga County, Ohio, ODNr Open File Report 96-xxx, 58pp.
- Guy, D.E., Benson, D.J. and Carter, C.H., 1997b. Lake Erie Shore Erosion and Flooding, Ottawa County, Ohio, ODNr Open File Report 96-xxx, 101pp.
- Guy, D.E., Benson, D.J. and Carter, C.H., 1997c. Lake Erie Shore Erosion and Flooding, Lorain County, Ohio, ODNr Open File Report 96-xxx, 54pp.



- Herdendorf, C.E., 1978. Descriptions of Sediment Samples and Cores From The Michigan and Ohio Waters of Lake Erie. Ohio State University Center for Lake Erie Area Research Technical Report No. 85.
- L.R. Johnston Associates, 1989. New York's Eastern Lake Ontario Sand Dunes - Resources, Problems and Management Guidelines. New York State Department of State, Division of Coastal Resources and Waterfront Revitalization, 148pp.
- Occhietti, S., 1989. Quarternary Geology of the St. Lawrence Valley and Adjacent Appalachian Subregion. In: Fulton, R.J. (ed.), Quarternary Geology of Canada and Greenland, Geological Survey of Canada, No. 1, Chapter 4.
- Pair, D., Karrow, P.F., and Clark, P.U., 1990. History of the Champlain Sea in the Central St. Lawrence Lowland, New York and It's Relationship to Water Levels in the Lake Ontario Basin. In: Gadd, N.R. (ed.), The Late Quaternary Development of the Champlain Sea Basin, Geological Association of Canada Special Paper 35, p.107-123.
- Seaway Trail Inc., 1991. The Nautical Seaway Trail - Chartbook and Waterfront Guide to New York State's Great Lakes - St. Lawrence River Region. Blue Heron Enterprises Inc., Hammond, New York, 119pp.
- Stewart, C.J., (1997). Development Of A Revised Great Lakes Shoreline Classification System And Recommendations For Application To The Lake Michigan Shoreline - Lake Michigan Potential Damages Study. VGI Vision Group International Consulting Report prepared for the U.S. Army Corps of Engineers – Detroit District, 18pp.
- Stewart, C.J., (1998a). A Revised Geomorphic, Shore Protection and Nearshore Classification of the Lake Michigan Shoreline - Lake Michigan Potential Damages Study. VGI Vision Group International Consulting Report prepared for the U.S. Army Corps of Engineers – Detroit District, 19pp.
- Stewart, C.J., (1998b). Recession Rate Analysis System Version 2.0 - User Manual and Summary of Updates – Lake Michigan Potential Damages Study. VGI Vision Group International Consulting Report prepared for the U.S. Army Corps of Engineers – Detroit District.



- Stewart, C.J., (1998c). Lake Ontario and Lake Erie Data Collection Activities - Lower Great Lakes Erosion Study. VGI Vision Group International Consulting Report Prepared for the U.S. Army Corps of Engineers - Buffalo District, 54pp, plus Appendices.
- Stewart, C.J., (1998d). Lake Ontario and Lake Erie Data Collection Activities - Lower Great Lakes Erosion Study, Appendix 8 - Lake Erie and Ontario Coastal Site Visits - Descriptions, Assessments, Photos, Field Notes. VGI Vision Group International Consulting Report Prepared for the U.S. Army Corps of Engineers - Buffalo District, 88pp.
- Stewart, C.J. and Pope, J., (1993). Erosion Processes Task Group Report. Report Prepared for the Erosion Processes Task Group, Working Committee 2, Phase II, International Joint Commission Water Level Reference Study, 99pp., plus Appendices.
- Sutton, R.G., Lewis, T.L., and Woodrow, D.L., 1970. Near-shore Sediments in Southern Lake Ontario, Their Dispersal Patterns and Economic Potential. Proceedings of the 13<sup>th</sup> Conference on Great Lakes Research, 1970: p.308-318.
- Terasmae, J., 1965. Surficial Geology of the Cornwall and St. Lawrence Seaway Project Areas, Ontario. Geological Survey of Canada Bulletin No. 121, 54pp.



## APPENDIX I

### GREAT LAKES - ST.LAWRENCE RIVER SHORELINE CLASSIFICATION SCHEME (1999)

#### Geomorphic Classification

Key changes here were to expand the bluff and bank categories of the original scheme to incorporate aspects of the bluffs physical character (i.e., homogeneous or composite), as well as it's sand content. As a result, a number of new sub-classes of bluff type are identified.

1. Sand or Cohesive Bluffs (define heights and other information as separate attributes)
  - 1a. Homogeneous Bluffs (sand content 0-20%)
  - 1b. Homogeneous Bluffs (sand content 20-50%)
  - 1c. Homogeneous Bluffs (sand content >50%)
  - 1d. Composite Bluffs (sand content 0-20%)
  - 1e. Composite Bluffs (sand content 20-50%)
  - 1f. Composite Bluffs (sand content >50%)
2. Sand or Cohesive Bluffs With Beach (define heights and other information as separate attributes)
  - 2a. Homogeneous Bluffs (sand content 0-20%)
  - 2b. Homogeneous Bluffs (sand content 20-50%)
  - 2c. Homogeneous Bluffs (sand content >50%)
  - 2d. Composite Bluffs (sand content 0-20%)
  - 2e. Composite Bluffs (sand content 20-50%)
  - 2f. Composite Bluffs (sand content >50%)
3. Low Bank
  - 3a. (Sand content 0-20%)
  - 3b. (Sand content 20-50%)
  - 3c. (Sand content >50%)
4. Baymouth Barrier
5. Sandy Beach / Dune
6. Coarse Beaches
7. Bedrock (Resistant)
8. Bedrock (Non-Resistant)
9. Open Shoreline Wetlands



- 10. Artificial
- 11. Unclassified

### Shore Protection Classification

In this tier of the classification, more detail has been provided to gain insight into the "purpose" of the protection (e.g., armoring or erosion control), the "type" of structure (e.g., revetment or seawall), and the "quality" of the structure ( the "Quality Qualifier"). This has resulted in a much expanded scheme than the original.

- 1. Coastal Armoring
  - 1a. Revetments
  - 1b. Seawalls / Bulkheads
- 2. Beach Erosion Control Devices
  - 2a. Groins
  - 2b. Jetties (littoral barriers?)
  - 2c. Offshore Breakwaters
  - 2d. Perched Beaches
- 3. Non-Structural
  - 3a. Beach Nourishment
  - 3b. Vegetation Planting / Bioengineering
  - 3c. Slope Grading / Bluff Stabilization
- 4. Protected Wetlands
- 5. Ad-Hoc
  - 5a. Concrete Rubble
  - 5b. Other Materials
- 6. Unclassified
- 7. No Shore Protection

### Quality Qualifier

- 1 - Full Effect - >45 year predicted lifespan
- 2 - Some Effect - 5 - 45 year predicted lifespan
- 3 - No Effect - 0-5 year predicted lifespan
- 4 - Unprotected - 0 years

All would be +/- 5 years



As an example, a shore protection type of 1A1, would be a revetment with a predicted lifespan of greater than 45 years.

### Nearshore Subaqueous Classification

Similar to the geomorphic classification, the goal here was to provide more detail as to the amount of sand covering the nearshore zone. Thus, key categories have been split to indicate three separate sand cover classifications.

1. Cohesive (Till)
  - 1a. Thick Sand Cover ( $>200 \text{ m}^3/\text{m}$ )
  - 1b. Moderate Sand Cover ( $50\text{-}200 \text{ m}^3/\text{m}$ )
  - 1c. Thin Sand Cover ( $<50 \text{ m}^3/\text{m}$ )
2. Cohesive (Lacustrine Clay)
  - 2a. Thick Sand Cover ( $>200 \text{ m}^3/\text{m}$ )
  - 2b. Moderate Sand Cover ( $50\text{-}200 \text{ m}^3/\text{m}$ )
  - 2c. Thin Sand Cover ( $<50 \text{ m}^3/\text{m}$ )
3. Cobble / Boulder Lag Over Cohesive
  - 3a. Thick Sand Cover ( $>200 \text{ m}^3/\text{m}$ )
  - 3b. Moderate Sand Cover ( $50\text{-}200 \text{ m}^3/\text{m}$ )
  - 3c. Thin Sand Cover ( $<50 \text{ m}^3/\text{m}$ )
4. Sandy
5. Bedrock (Resistant)
6. Bedrock (Non-Resistant)
7. Unclassified



## APPENDIX II

### KM x KM SHORELINE CLASSIFICATION DATA, LAKES ERIE AND ONTARIO, NIAGARA AND ST. LAWRENCE RIVERS